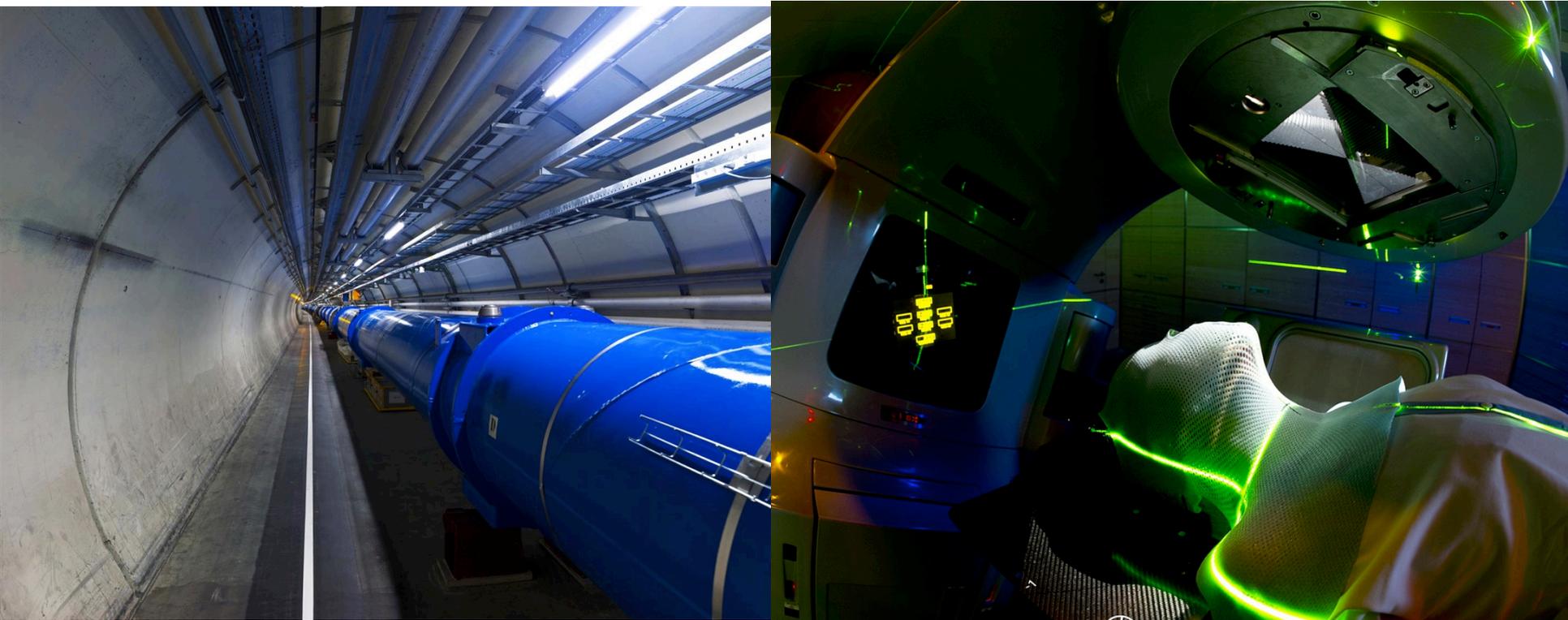
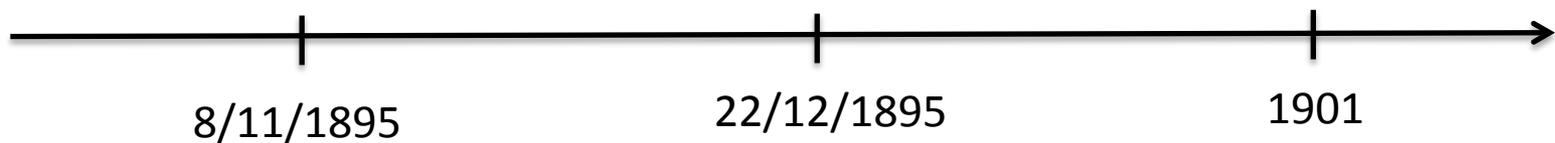
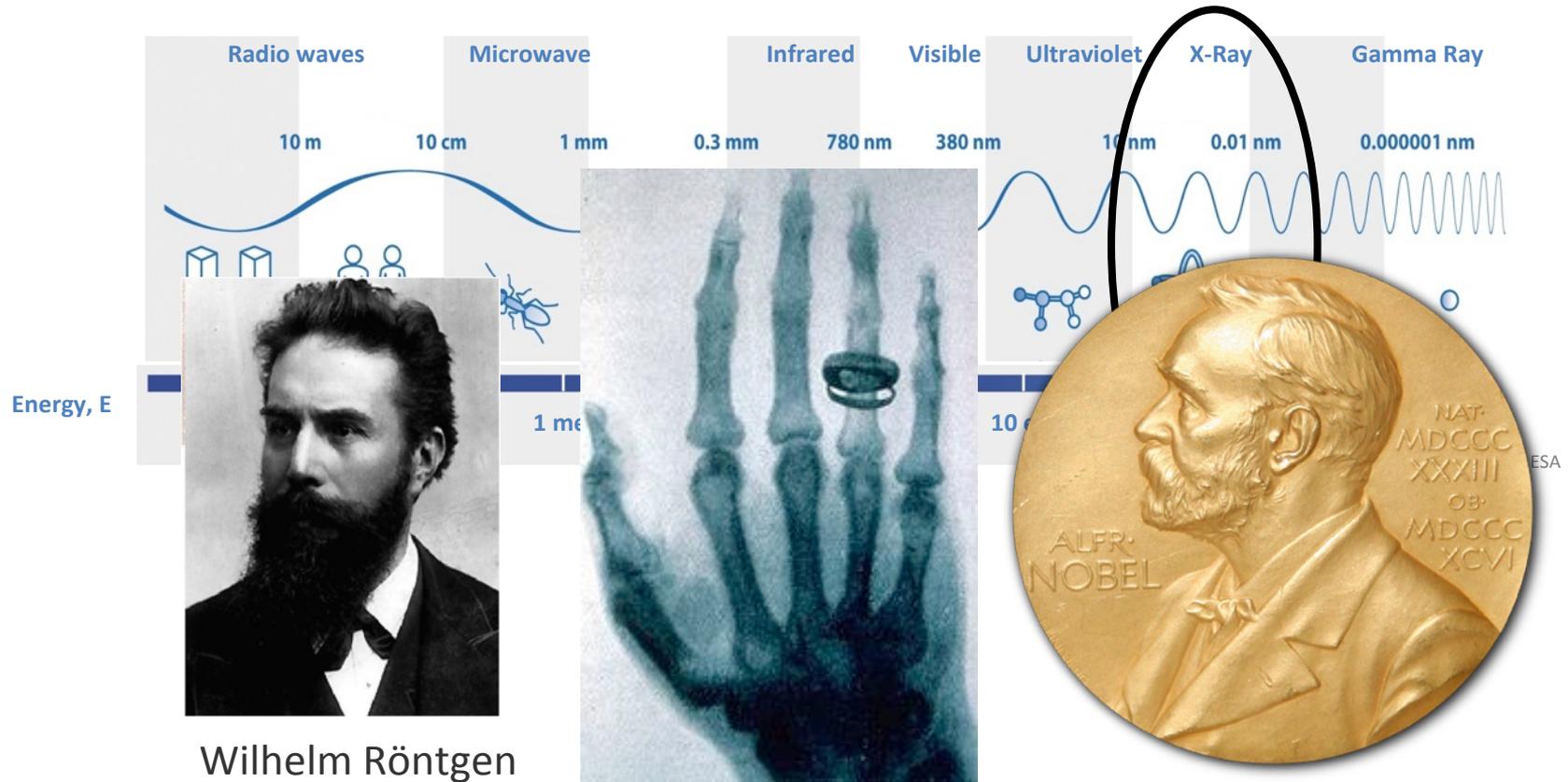


# From Physics to Medical Applications



Manjit Dosanjh, CERN  
[manjit.dosanjh@cern.ch](mailto:manjit.dosanjh@cern.ch)

# Modern medical physics– X-rays

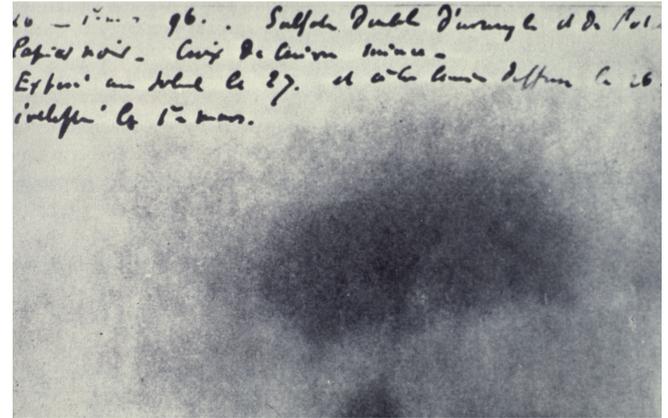


.....beginning of medical physics

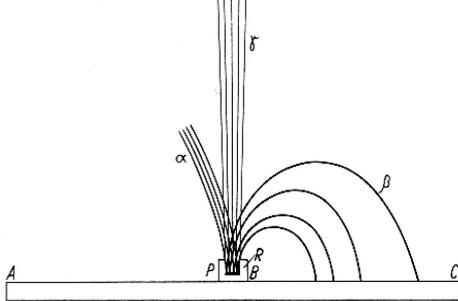


Henri Becquerel

**1896:**  
**Discovery of natural radioactivity**

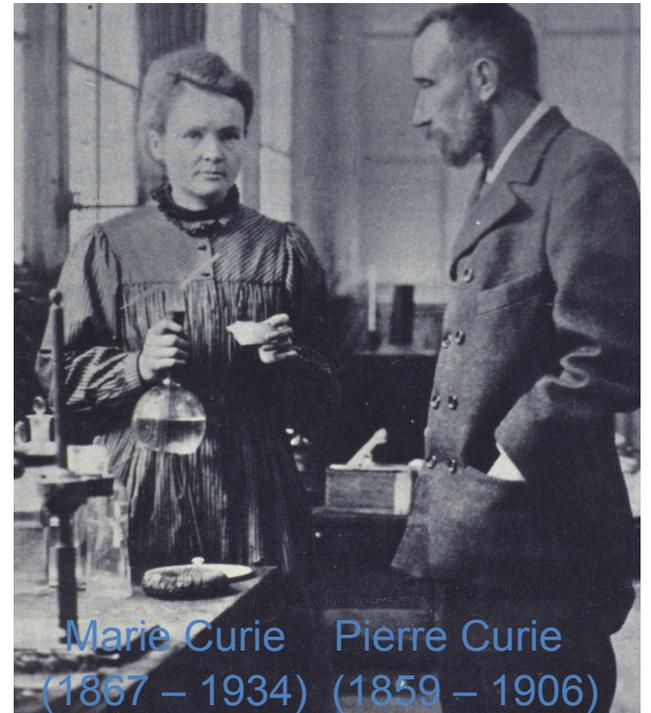


Thesis of Mme. Curie – 1904  
 $\alpha$ ,  $\beta$ ,  $\gamma$  in magnetic field



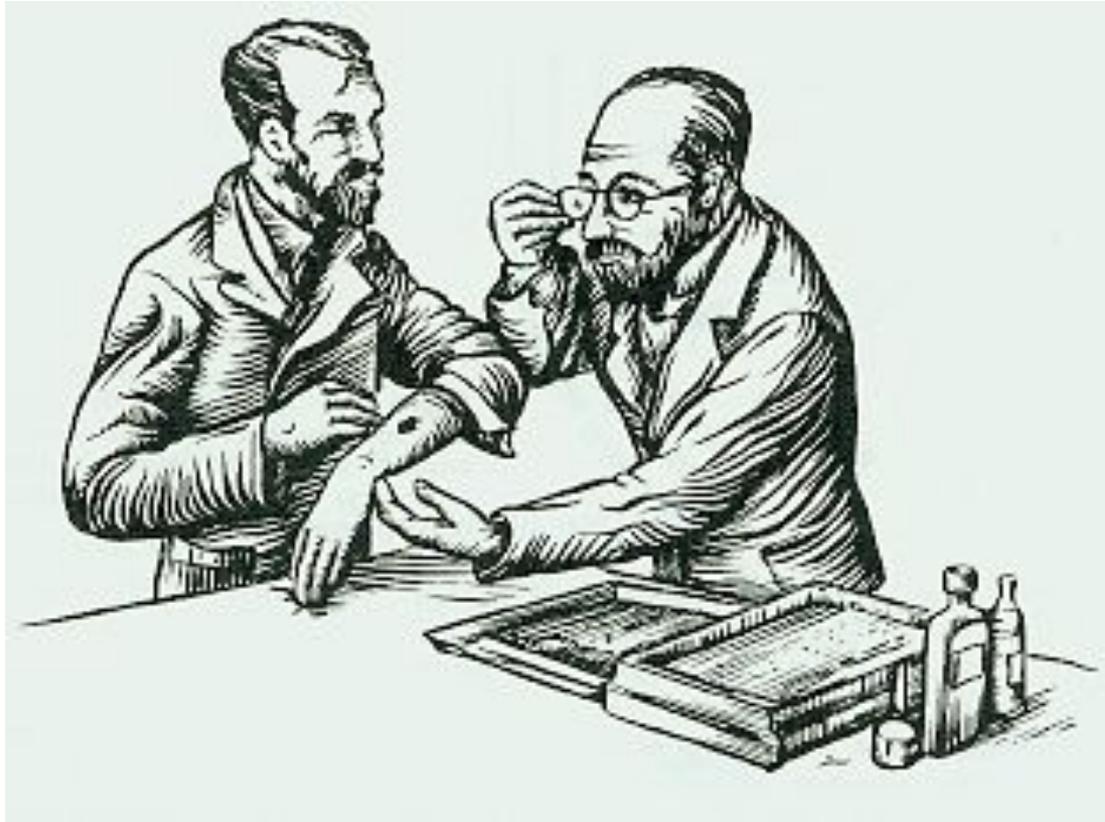
**1898: Discovery of radium**

**used immediately for “Brachytherapy”**



Marie Curie (1867 – 1934) Pierre Curie (1859 – 1906)

# First radiobiology experiment

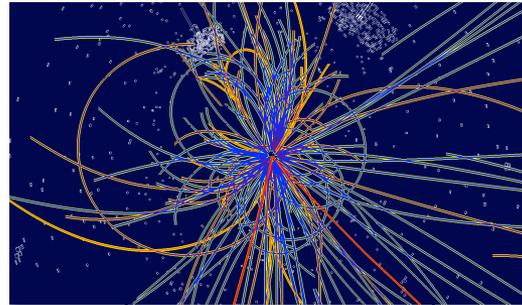


Pierre Curie and Henri Becquerel



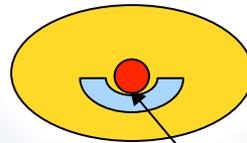
# CERN Technologies and innovation

## For health



Detecting particles

Accelerating particle beams



**CANCER**

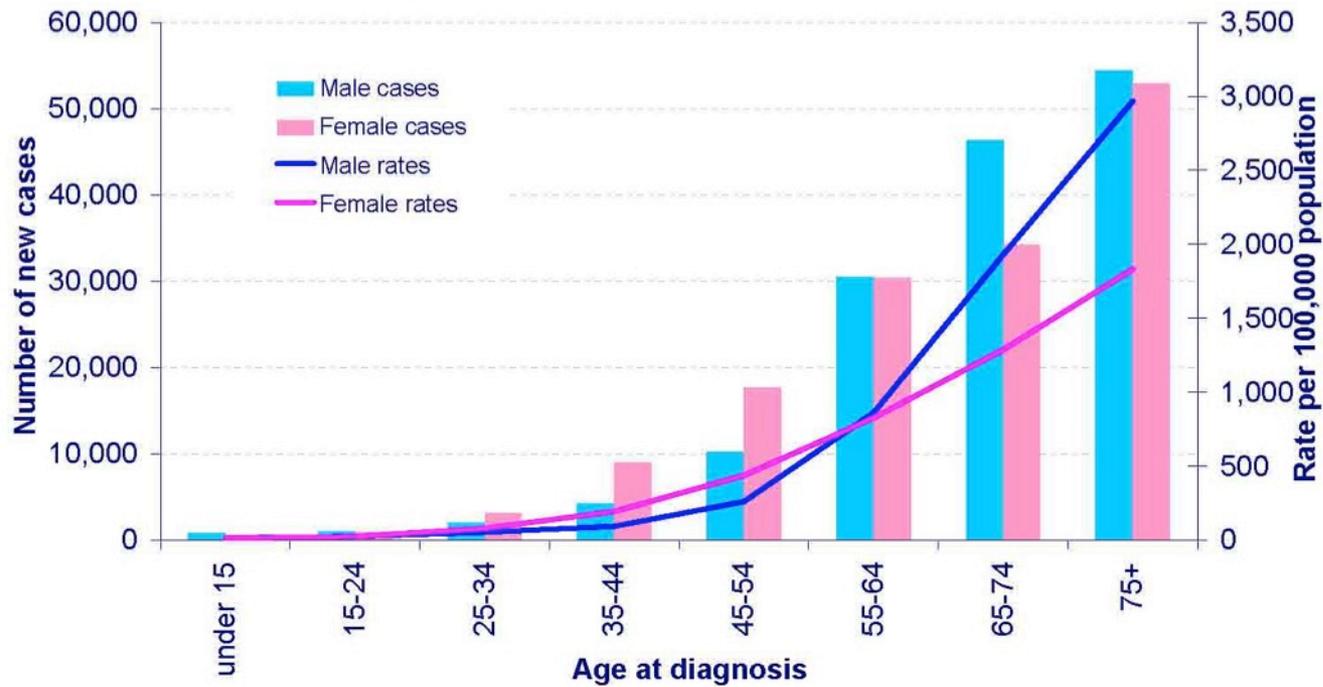
Large-scale computing (Grid)



# Cancer – a growing challenge

More than 3 million new cancer cases in Europe each year and 1.75 million associated deaths

Increase by 2030: 75% in developed countries and 90% in developing countries



# 4<sup>th</sup> Pillar Catalysing & facilitating collaboration

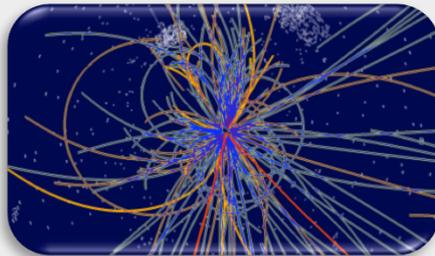
**Accelerating** particle beams



**Particle Therapy**



**Detecting** particles



**Medical imaging**



**Large scale computing (Grid)**



**Grid computing for medical data management and analysis**

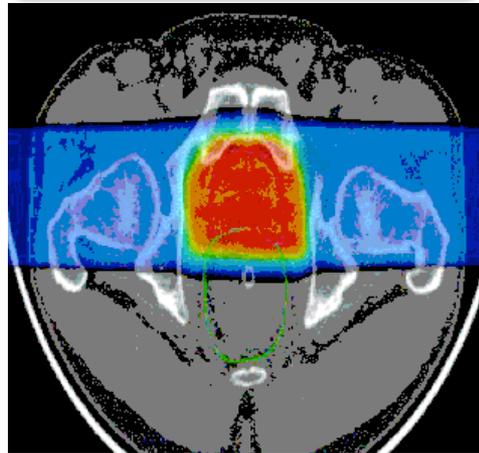


# Treatment options

Surgery



Radiotherapy



X-ray, IMRT, Brachytherapy,  
Hadrontherapy

Chemotherapy (+ others)



Hormones; Immunotherapy;  
Cell therapy; Genetic treatments; Novel  
specific targets (genetics..)

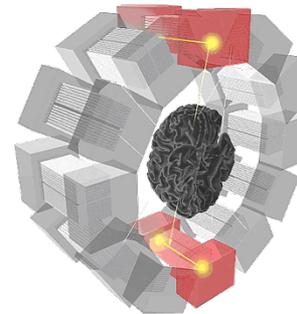


# No treatment without detection!

## Particle Detection



## Imaging

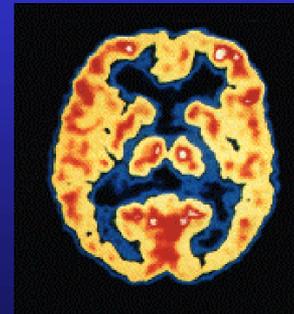


PET Scanner

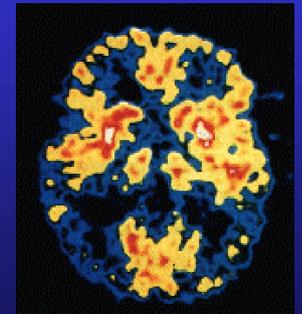
Breast imaging  
(ClearPEM)



Brain Metabolism in Alzheimer's  
Disease: PET Scan

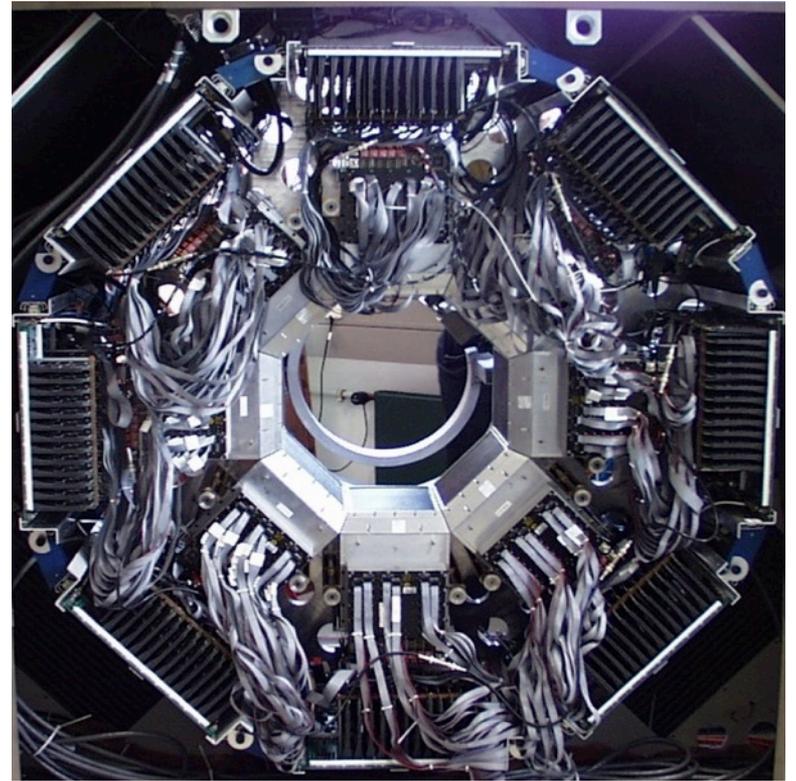


Normal Brain



Alzheimer's Disease

# The detector challenge



# CERN's role in detection and imaging

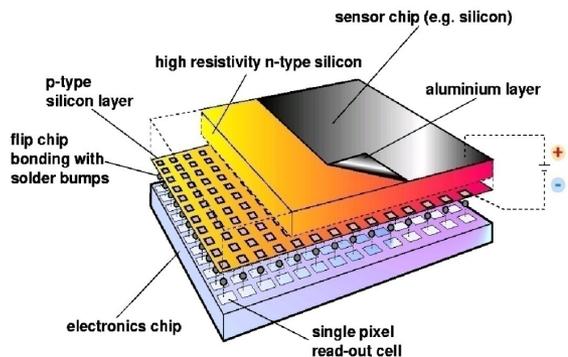
...

## Continuous development in particle physics:

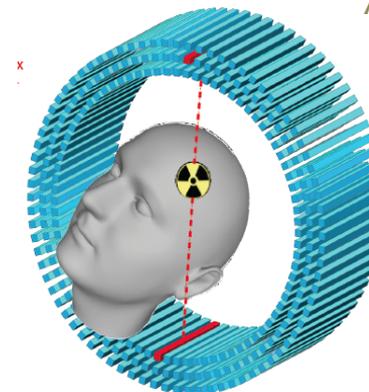
- Scintillating crystals (David Townsend .....
- Pixel detectors (Medipix collaboration)
- Diamond detectors
- Multi-wire proportional chambers/ GEMS (Charpak...)
- Resistive Plate Chambers for imaging

# CERN is contributing to accurate detection

## MEDIPIX



## AXPET



## Crystal Clear projects

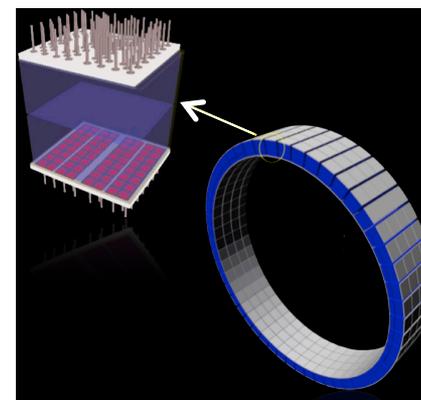
Courtesy of Paul Lecoq



ClearPET



ClearPEM & ClearPEM-Sonic



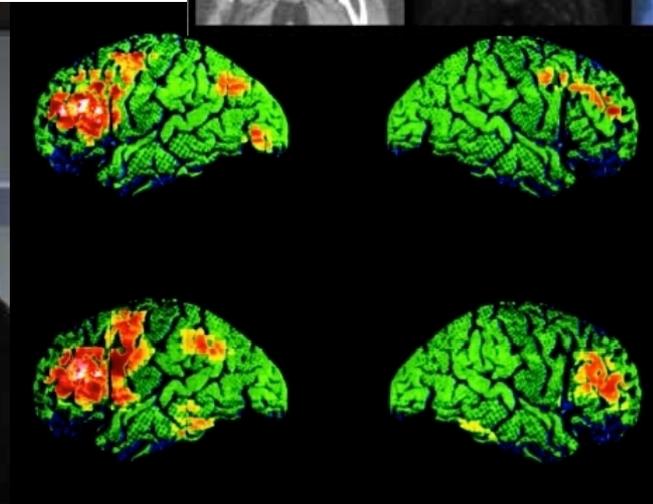
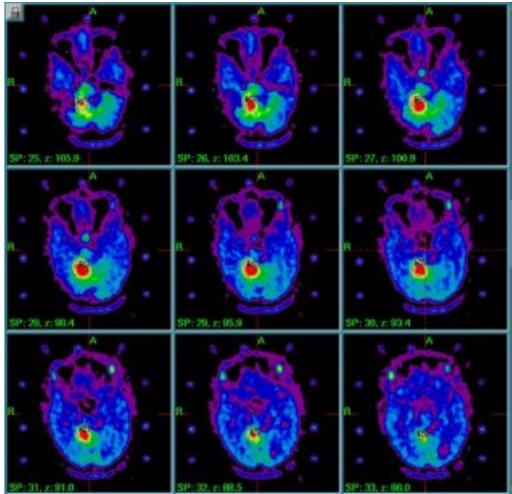
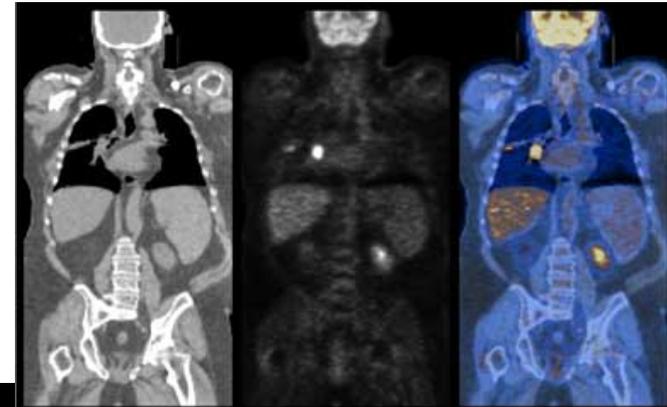
BrainPET

# PET: antimatter for clinical use

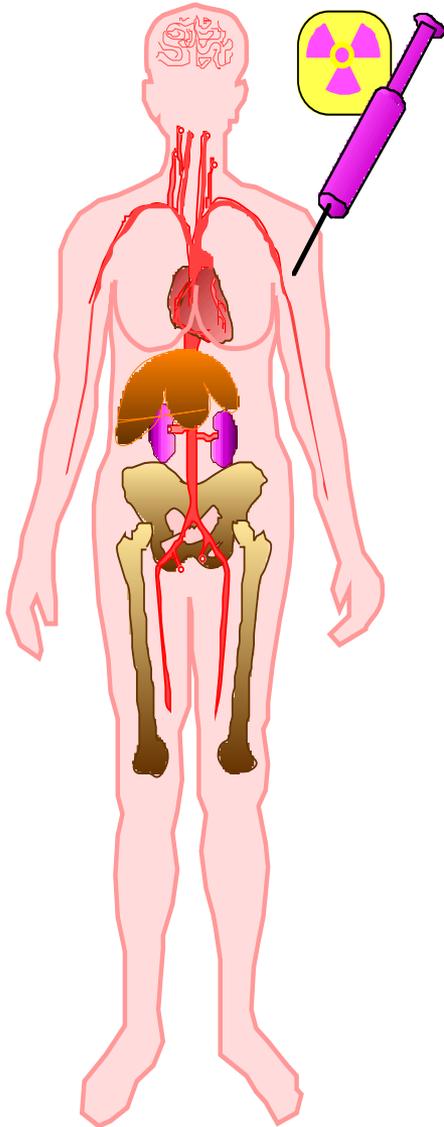


- Not only science-fiction

- ✦ Positrons are used in PET:
- ✦ PET = Positron Emission Tomography



# PET: how it works

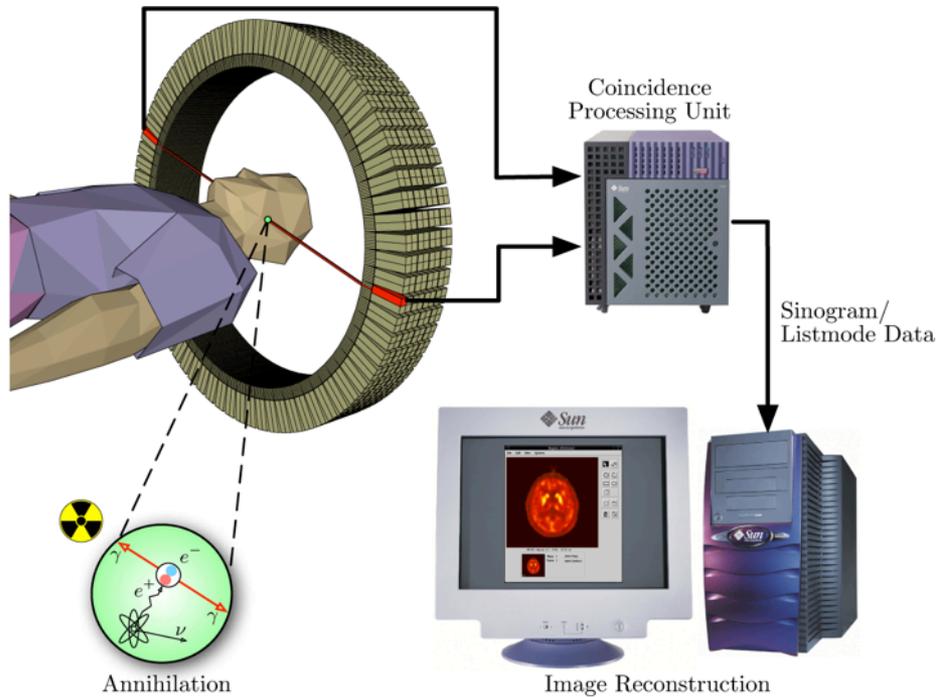


- Drug is labeled with positron ( $\beta^+$ ) emitting radionuclide.
- Drug localizes in patient according to metabolic properties of that drug.
- Trace (pico-molar) quantities of drug are sufficient.
- Radiation dose fairly small (<1 rem = 0.01 Sv).

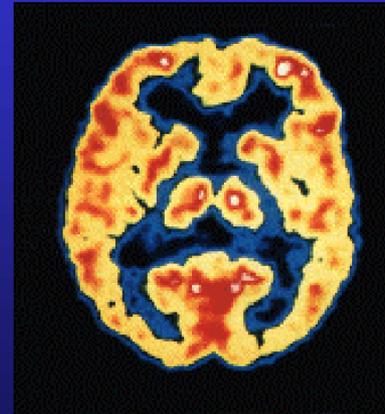
# PET – How it works

<http://www.nymus3d.nl/portfolio/animation/55>

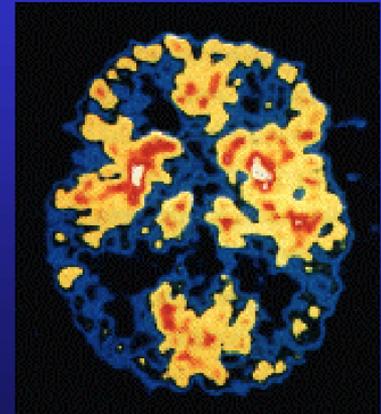
# PET Scan



## Brain Metabolism in Alzheimer's Disease: PET Scan



Normal Brain



Alzheimer's Disease

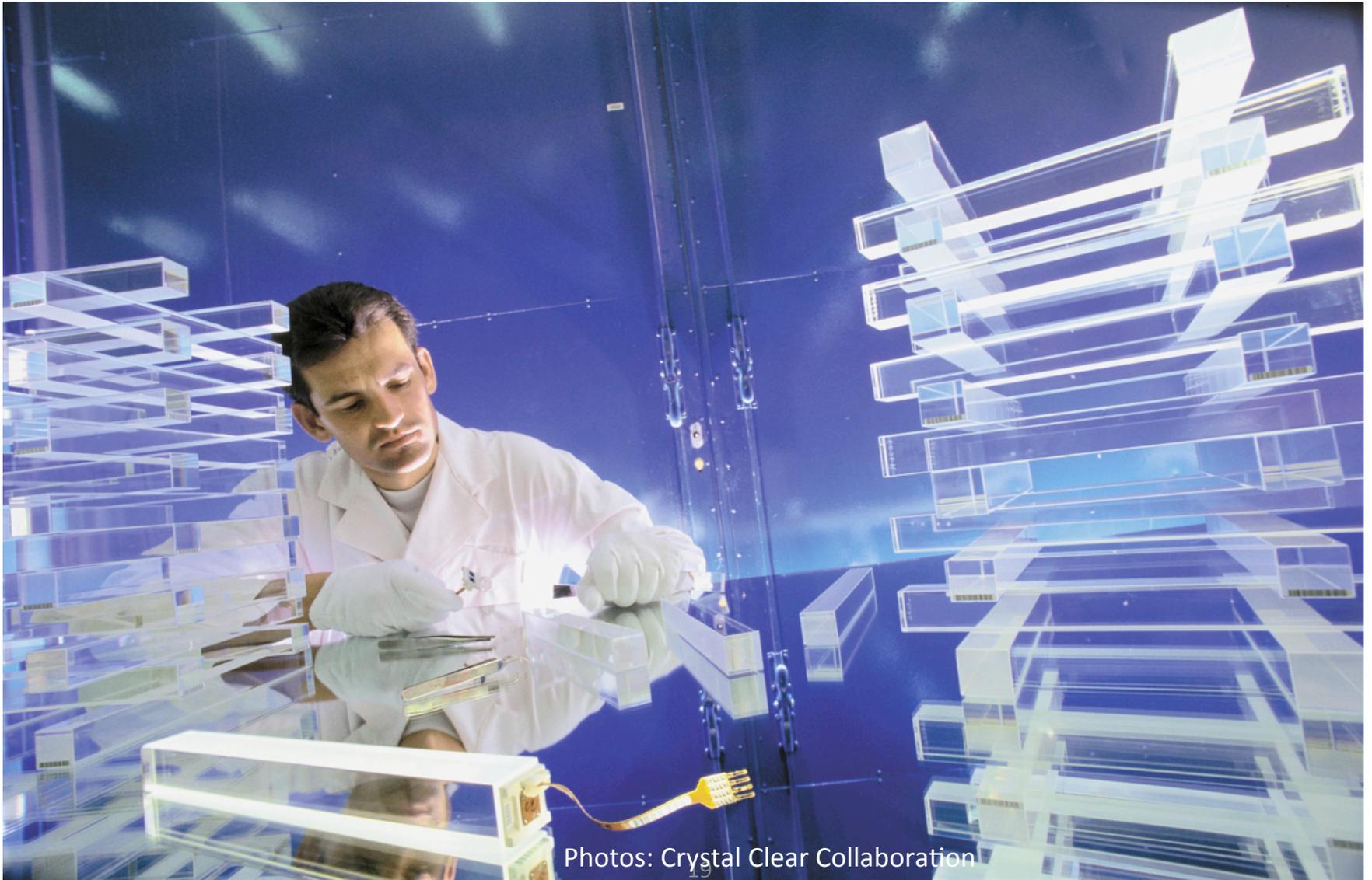
# Similar challenges

- New materials
- Compact
- low noise electronics
- Algorithms





# Crystal Clear Collaboration



Photos: Crystal Clear Collaboration

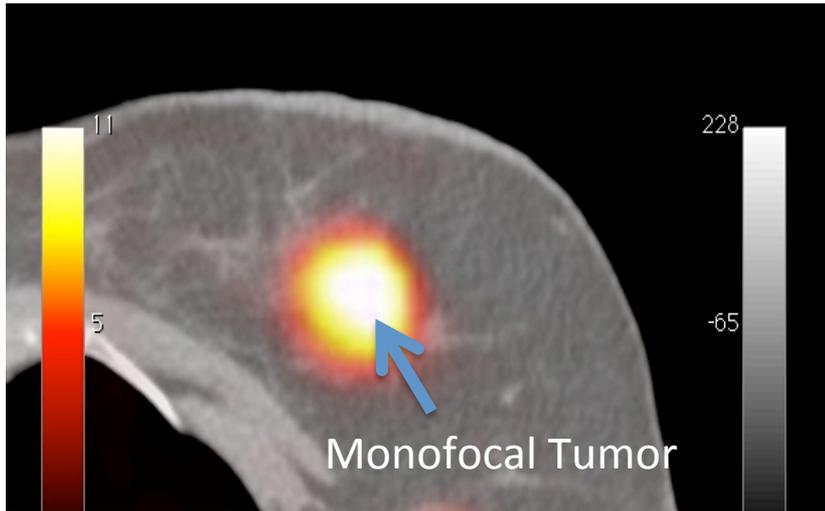
# ClearPEM



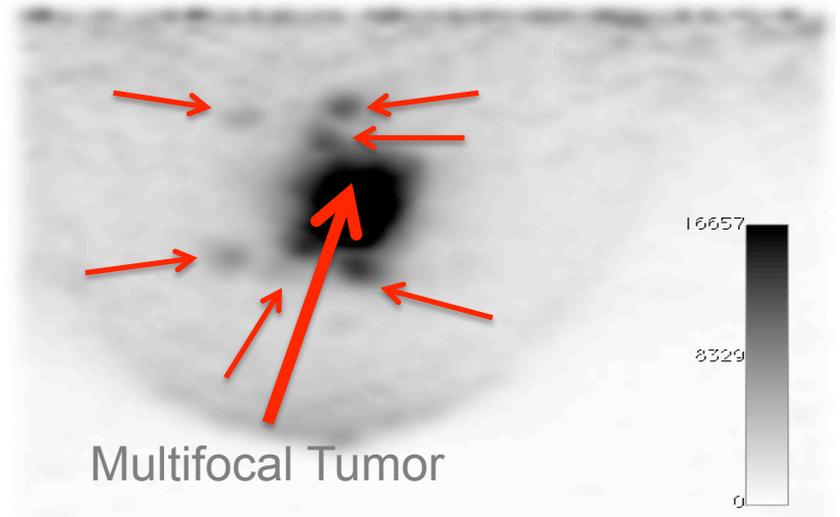
Photos: Crystal Clear Collaboration

PET for mammography: Crystal Clear Collaboration

# Breast Cancer Detection



**PET Wholebody**



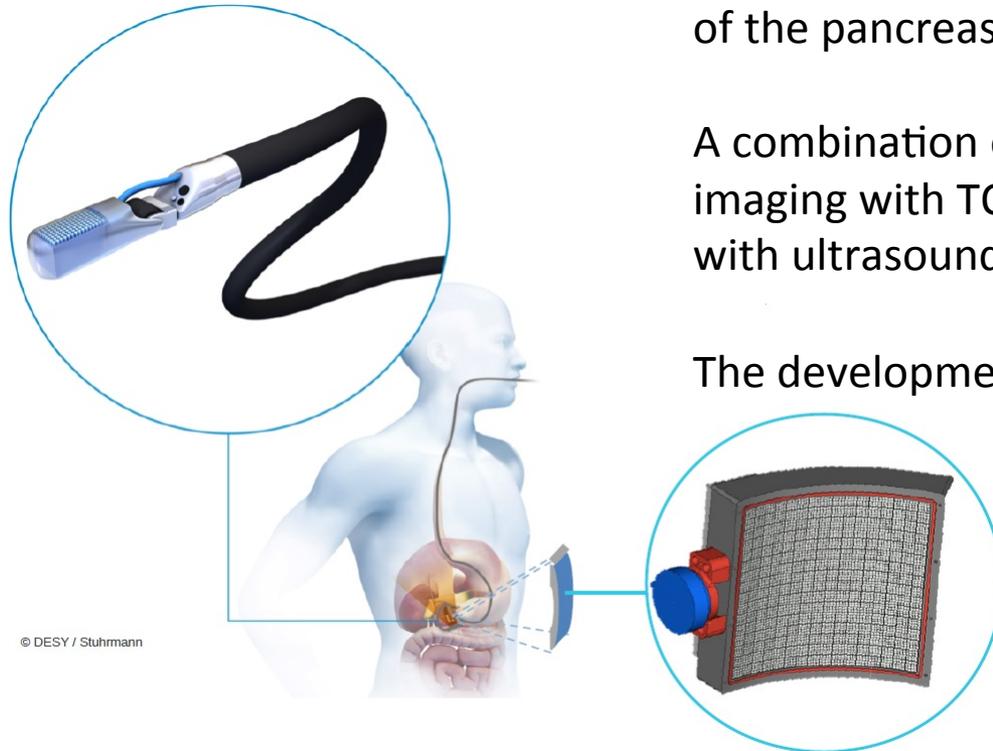
**ClearPEM dedicated Breast imaging**

# A new PET !

A novel imaging system for endoscopic exams of the pancreas or the prostate.

A combination of high resolution metabolic imaging with TOFPET and anatomical imaging with ultrasound.

The development of targeted biomarkers.

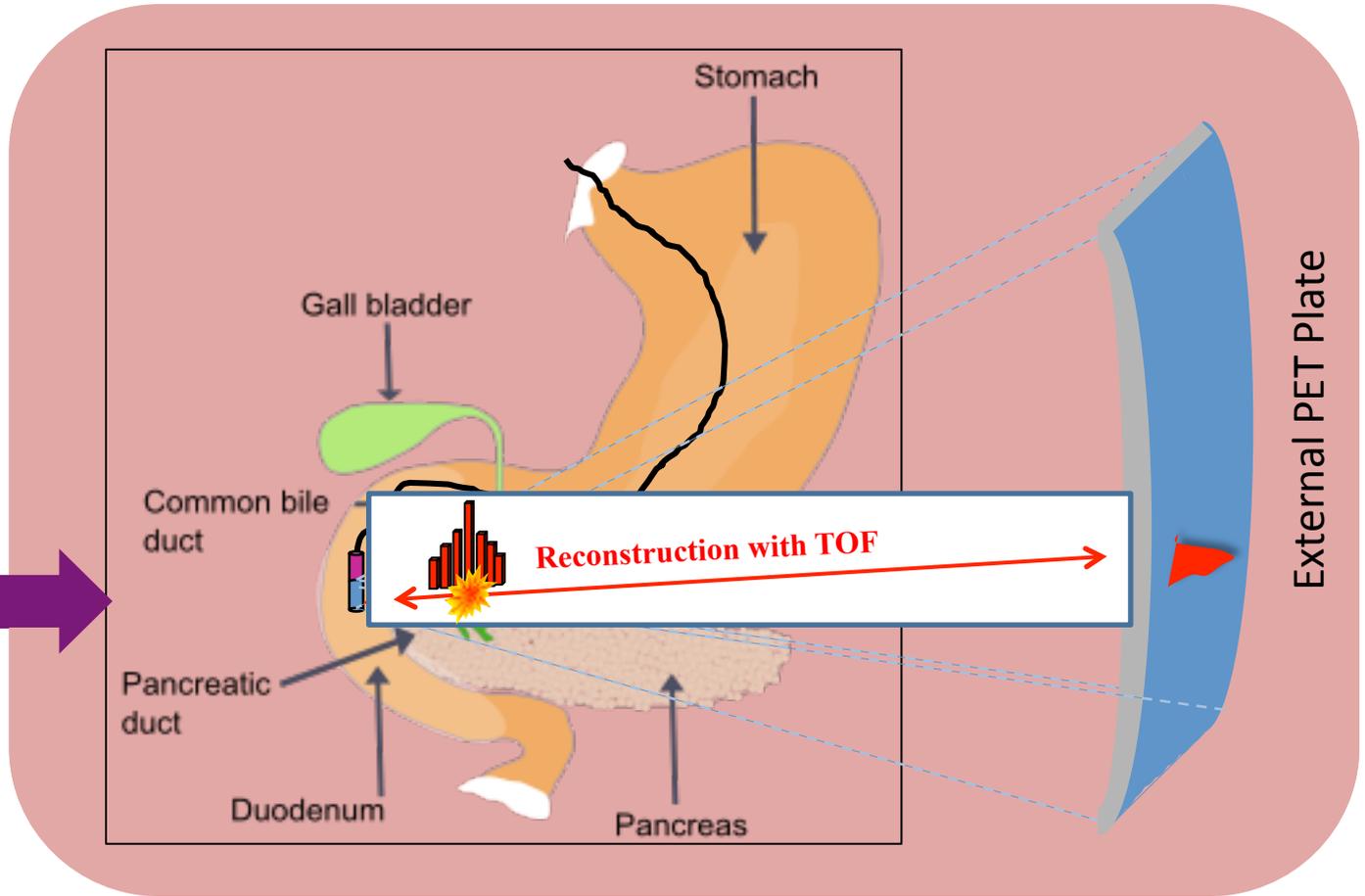
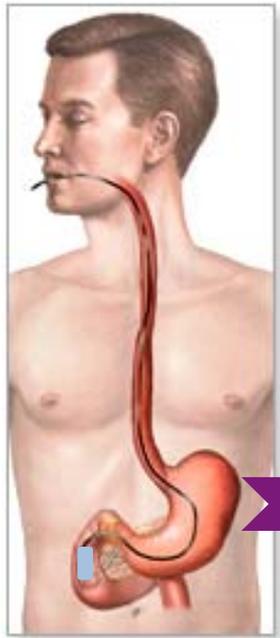


© DESY / Stuhmann

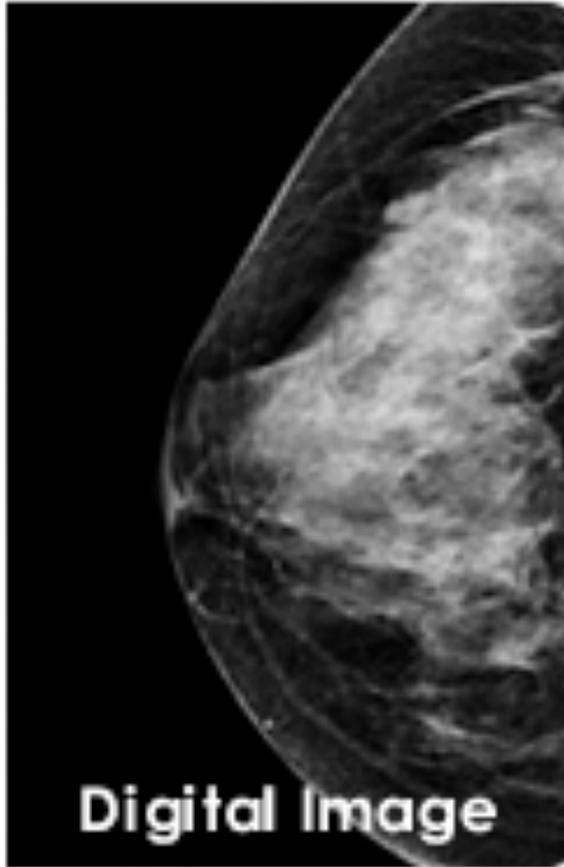
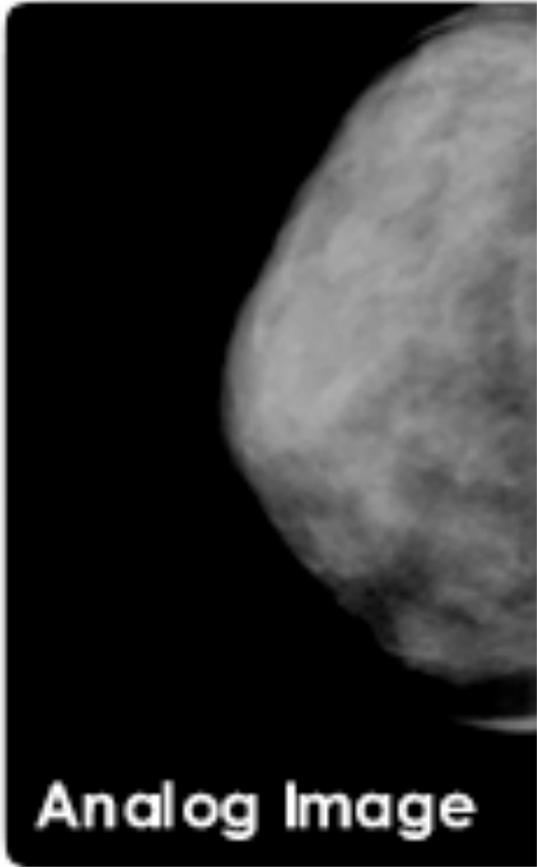
Courtesy of Paul Lecoq, : Crystal Clear Collaboration

# The prototype to build

## The principle

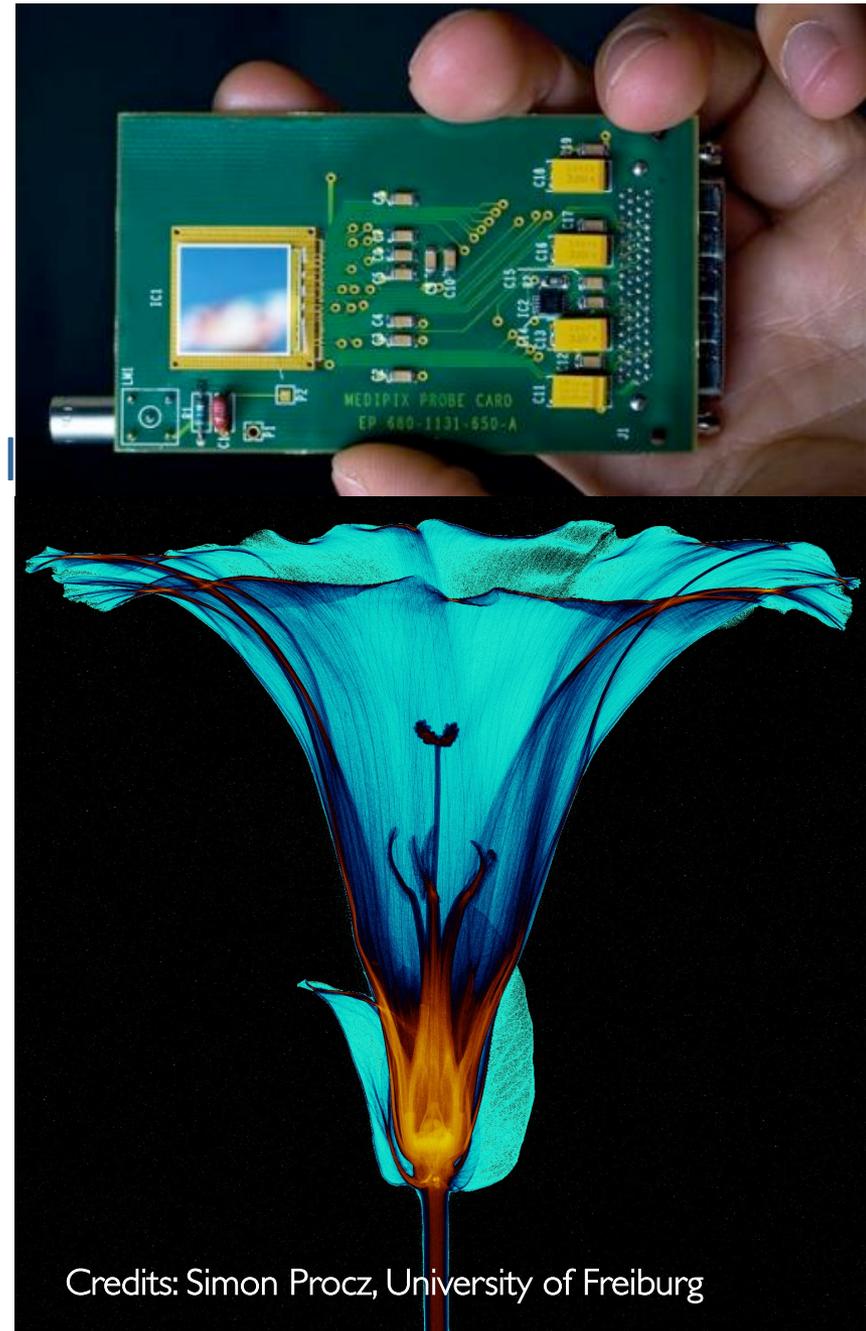


# Towards digital imaging



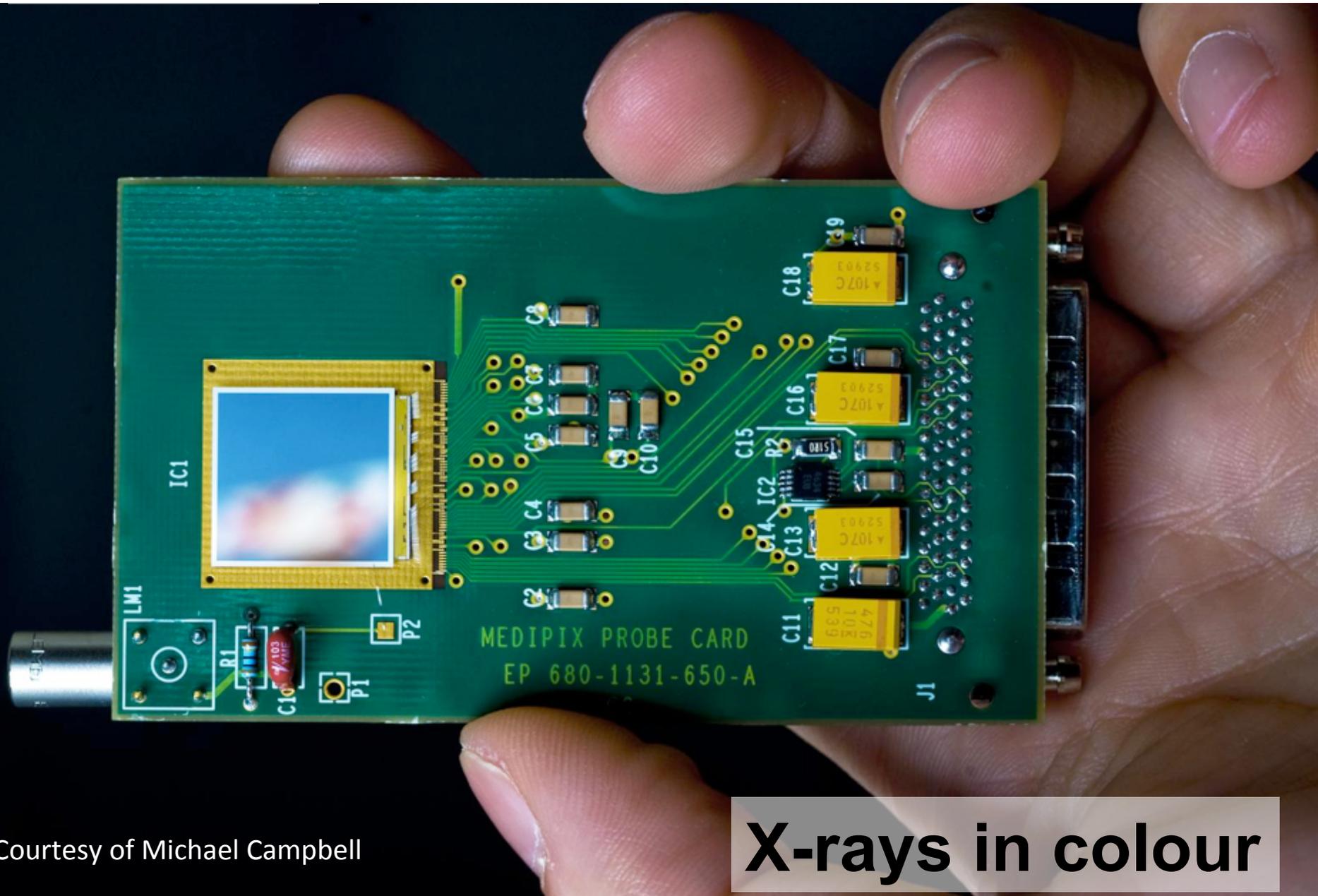
# Medipix

- High Energy Physics original development:
  - Particle track detectors
  - Allows counting of single photons in contrast to traditional charge integrating devices like film or CCD
- Main properties:
  - Fully digital device
  - Very high space resolution
  - Very fast photon counting
  - Good conversion efficiency of low energy X-rays



Credits: Simon Procz, University of Freiburg

# MEDIPIX



Courtesy of Michael Campbell

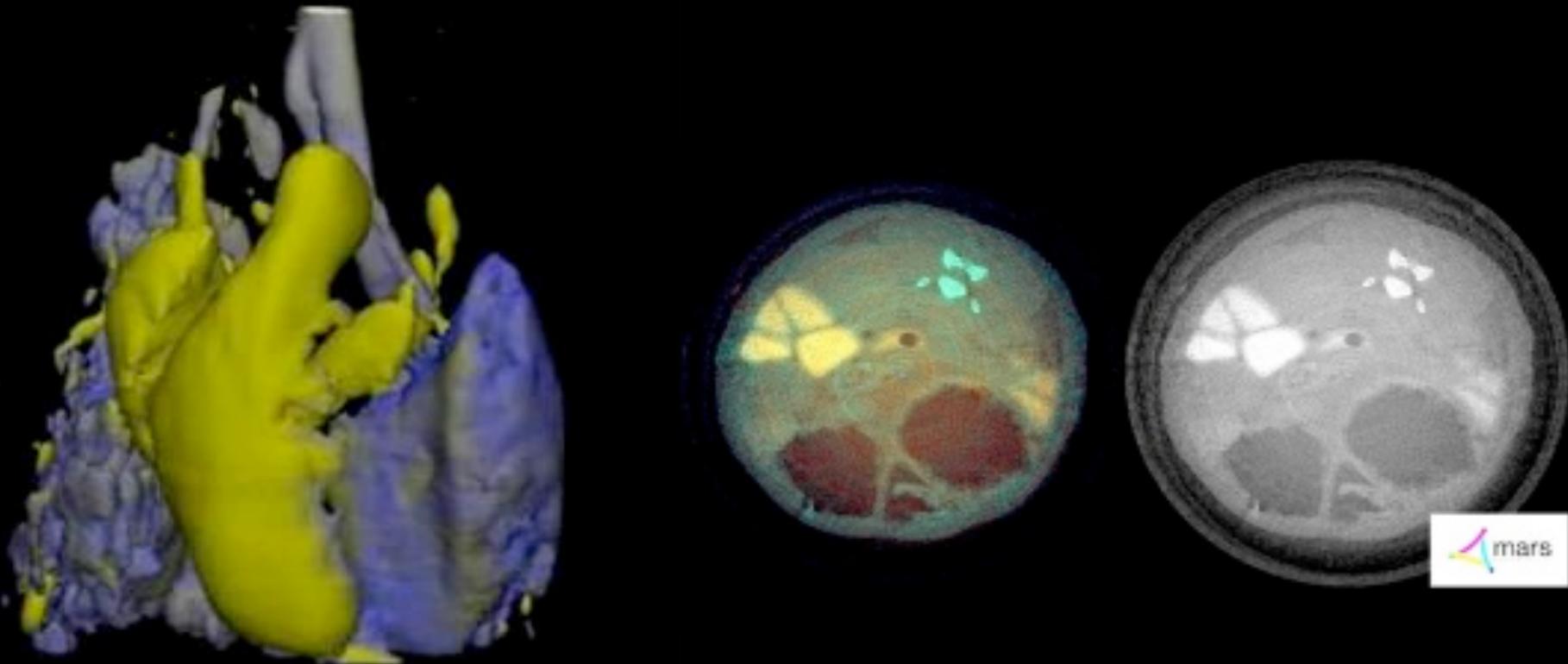
**X-rays in colour**

# The world in b/w or in colour?



Courtesy of Michael Campbell

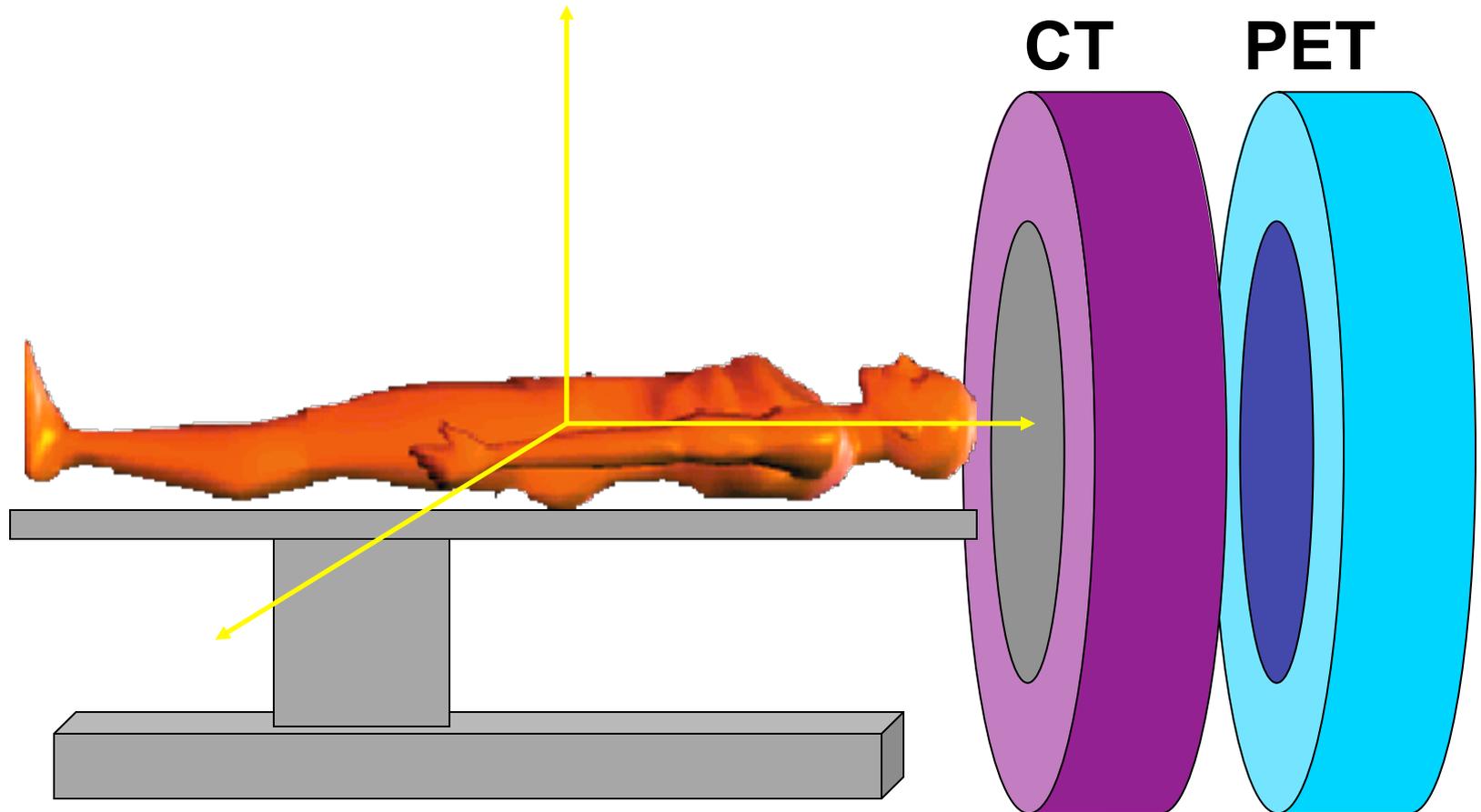
# MARS – MEDIPIX ALL RESOLUTION SYSTEM



(courtesy of MARS Bioimaging Ltd)

# Multi-modality imaging: PET-CT

*David Townsend*



# Multimodality imaging: CT with PET

Combining anatomic and functional imaging

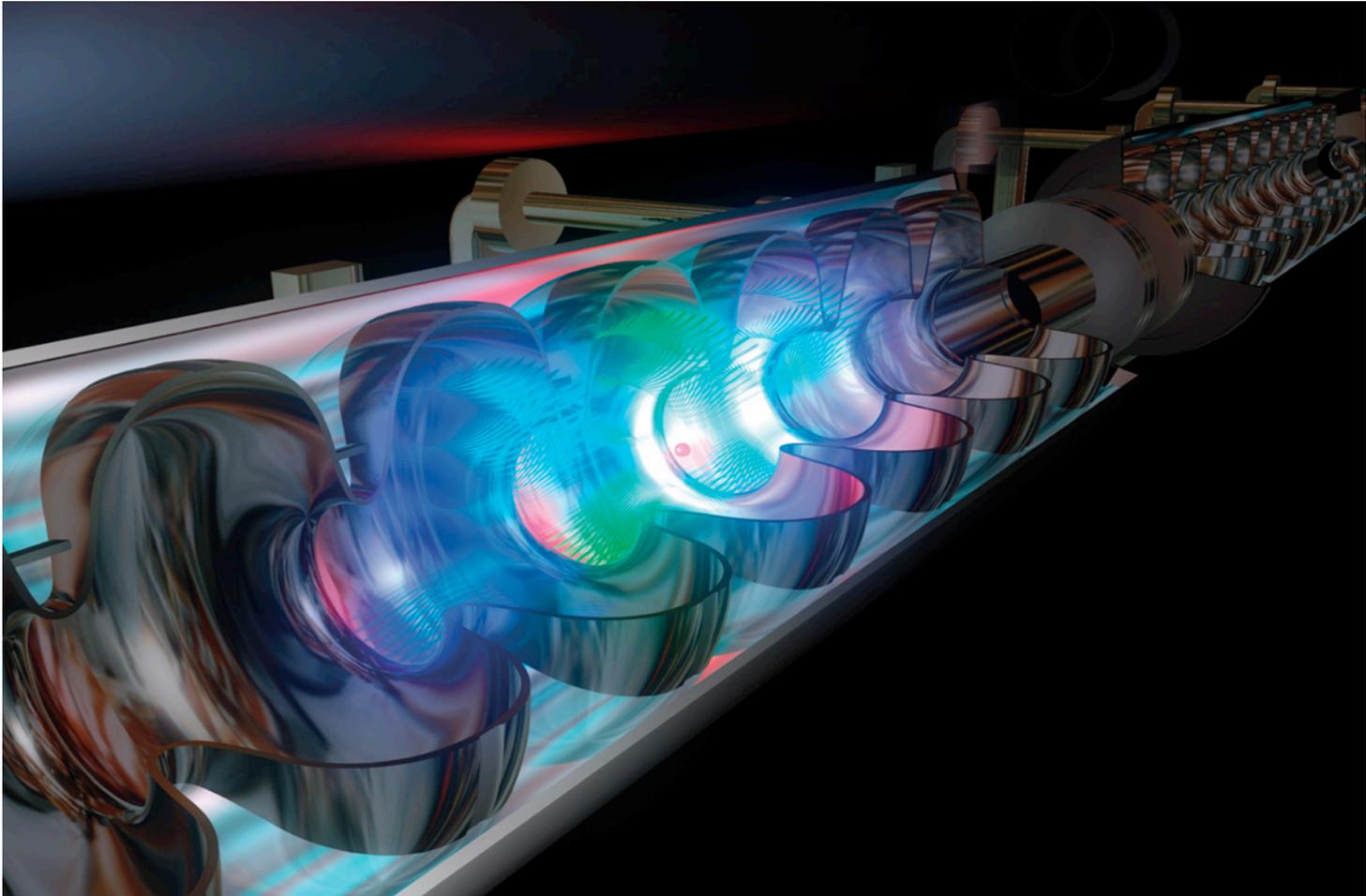
morphology

metabolism



David Townsend, CERN Physicist

# Accelerators for cancer treatment



# Use of Accelerators Today

## General industrial use:

Sterilisation, imaging

## Research Accelerators:

Particles, synchrotron light used in biomedical, physics, chemistry, biology, medical research.

## Radiotherapy:

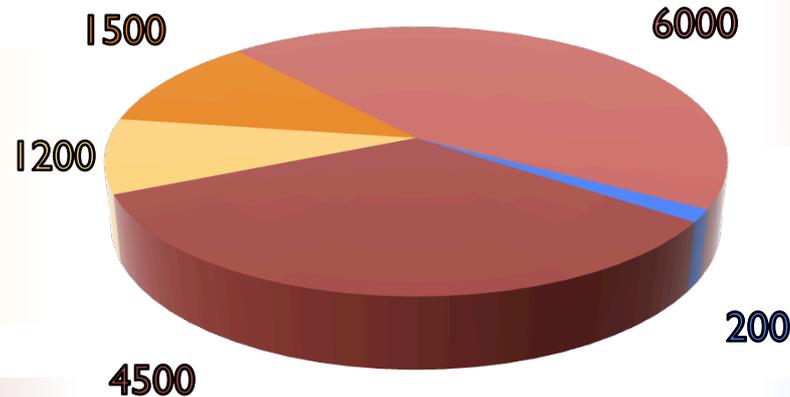
Cancer treatment with X-rays, protons and other particles.

## Ion implantation, surface modifications:

Controlled semiconductor doping; Changing properties of surfaces

## Radioisotope production:

Cancer treatment; imaging organs for medical use.



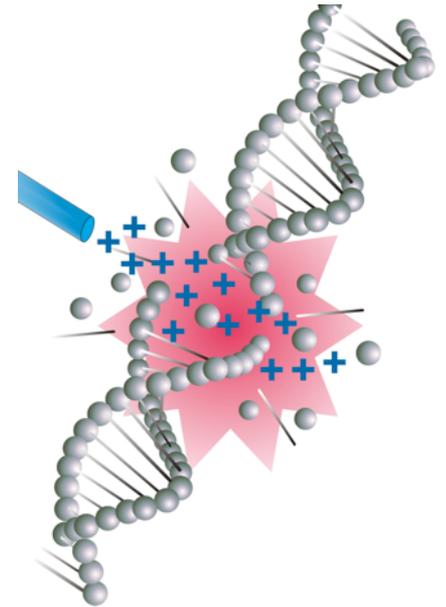
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~ 9000 of the 17000 accelerators operating in the World today are used for medicine.

# Conventional radiotherapy

- least expensive cancer treatment method
- most effective
- no substitute for RT in the near future
- rate of patients treated with RT is increasing

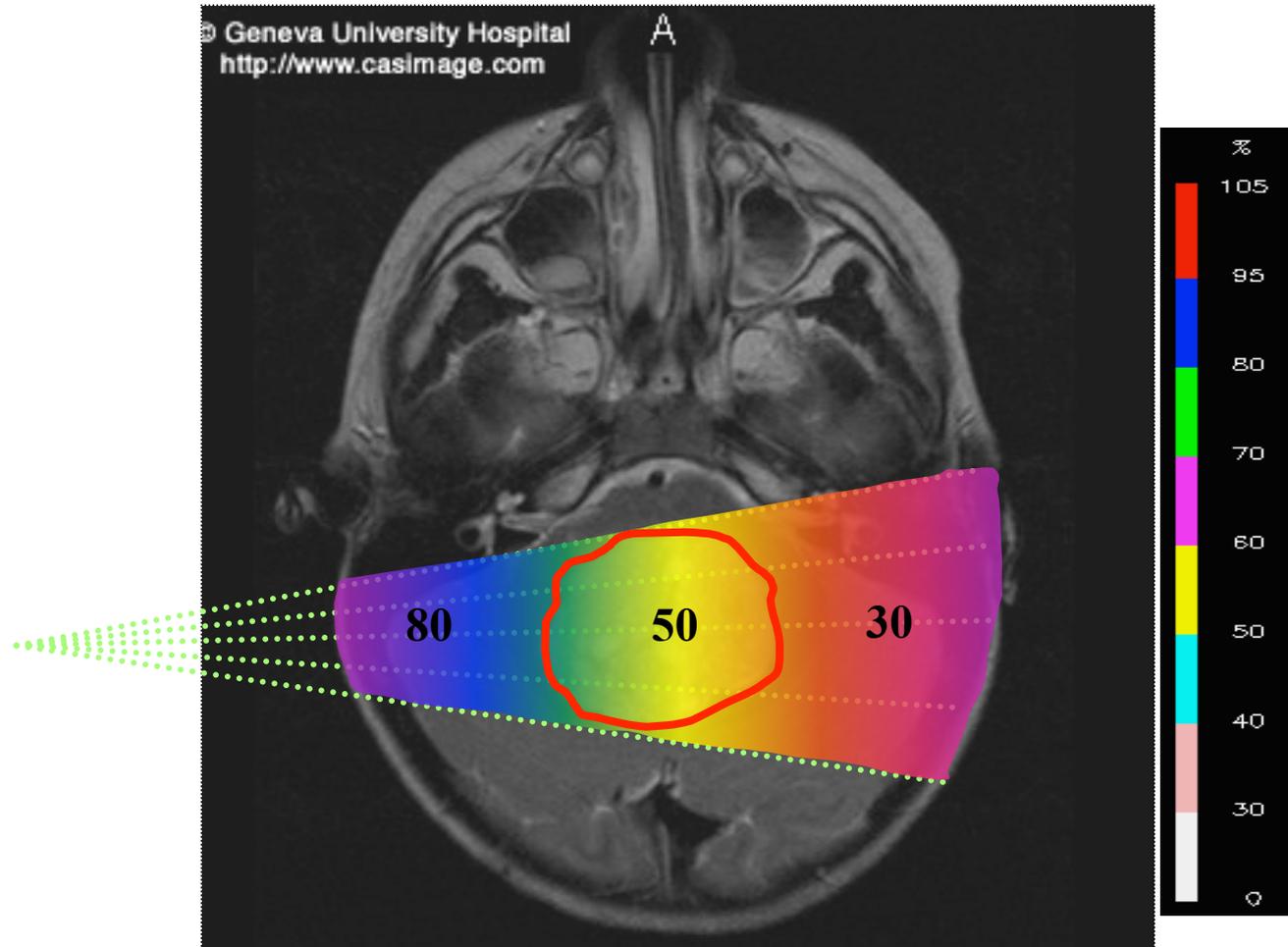
**30% of patients cancer comes back in the same location after RT**



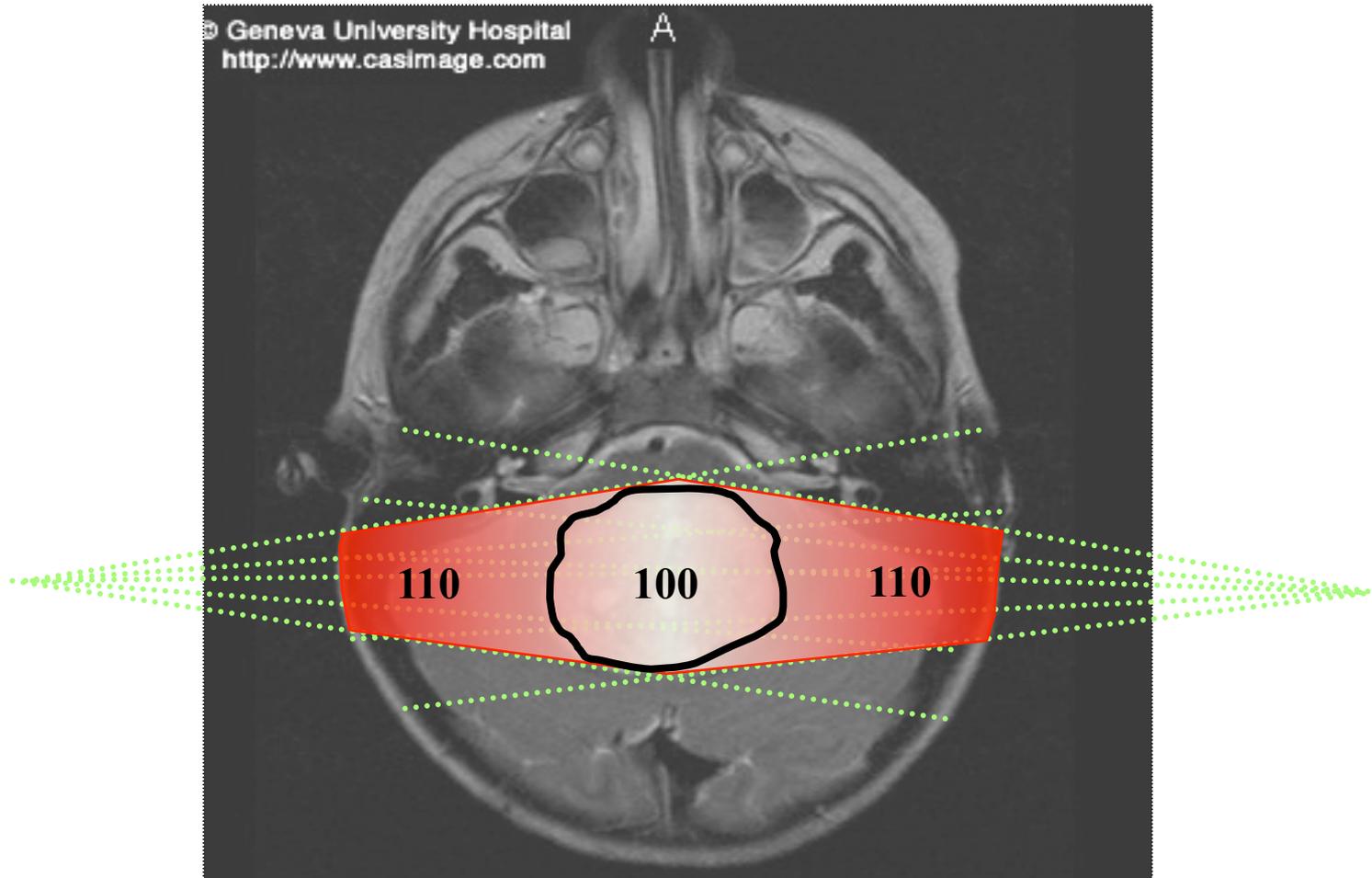
# How to improve outcome?

- Physics technologies: higher dose, more localised
- Imaging: accuracy, multimodality, real-time, organ motion
- Data: storage, analysis, sharing, patient referral, second opinion
- Biology: fractionation, radio-resistance, radio-sensitization
- Collaboration: cancer is a multidisciplinary field

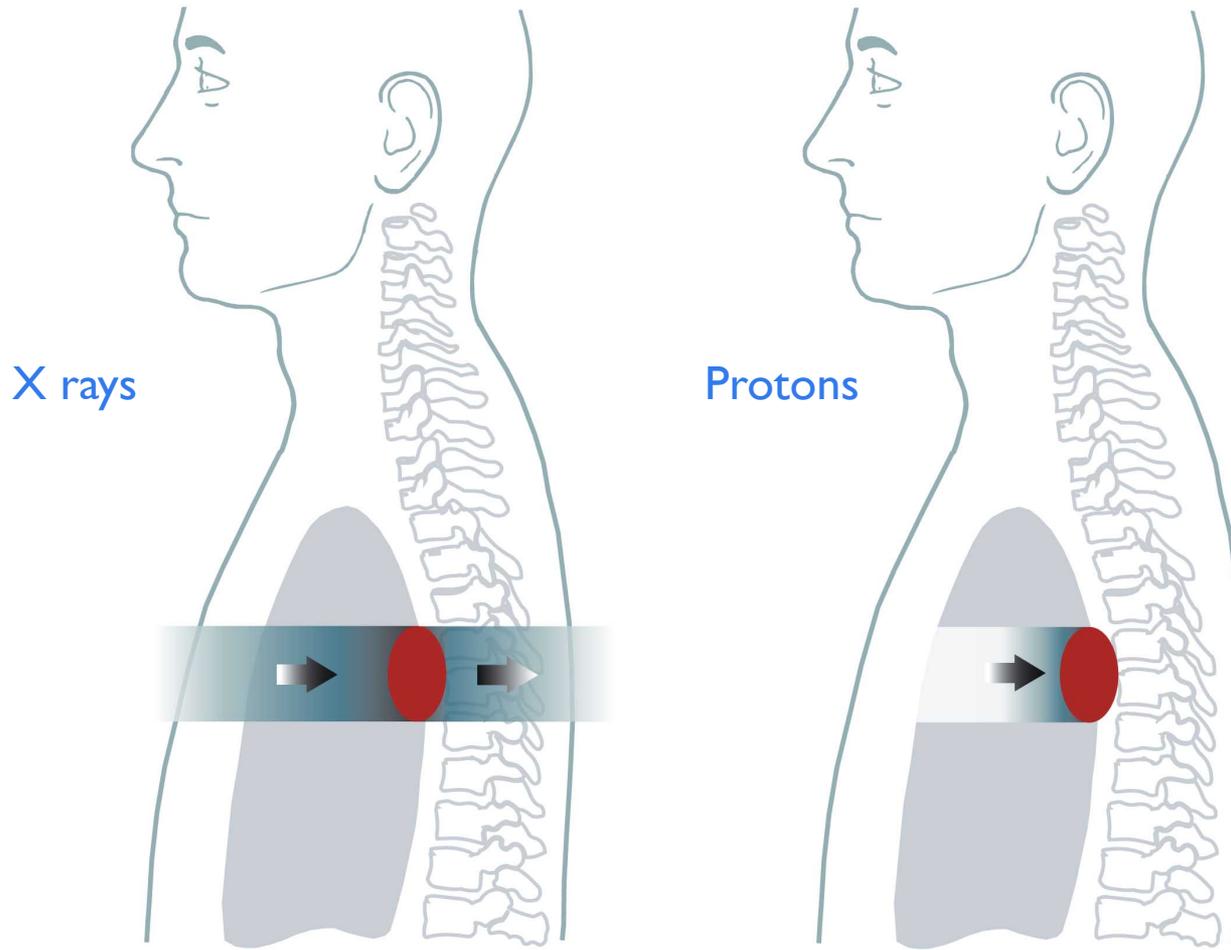
# Single beam of photons

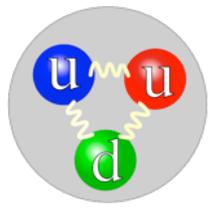


# 2 opposite photon beams



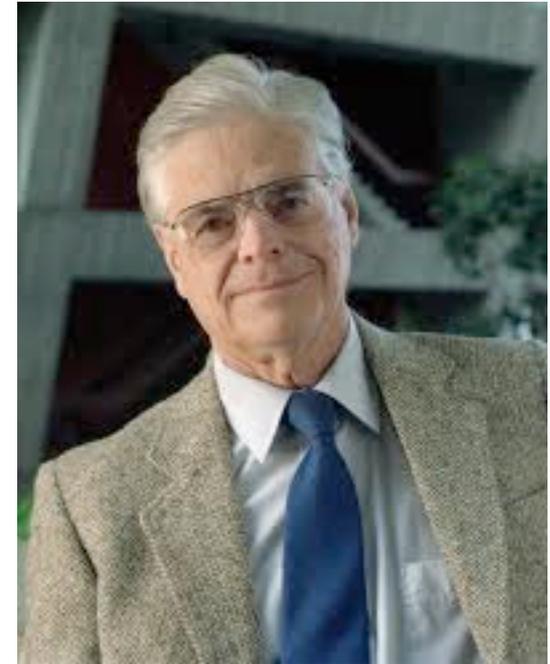
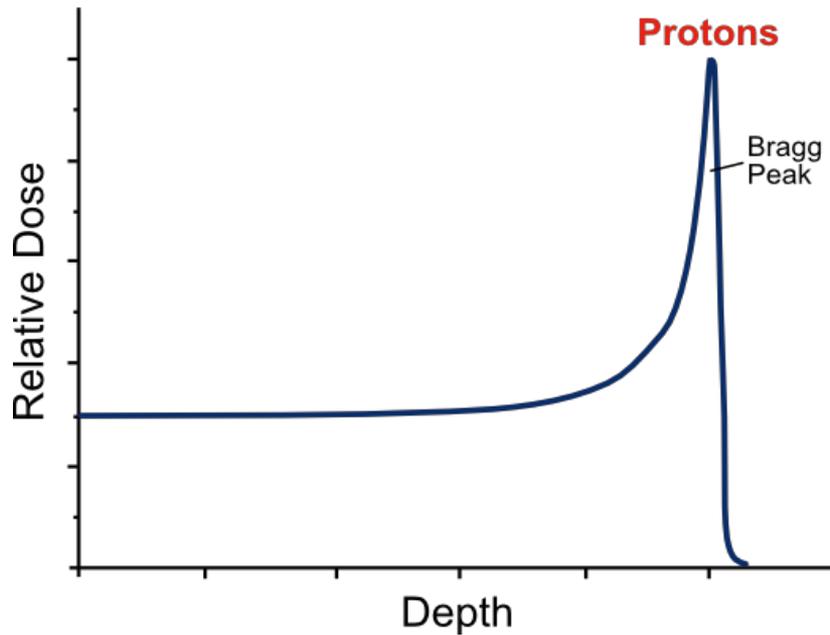
# HADRON THERAPY





# Alternative – Hadron Therapy

- 1946: Robert Wilson  
Protons can be used clinically



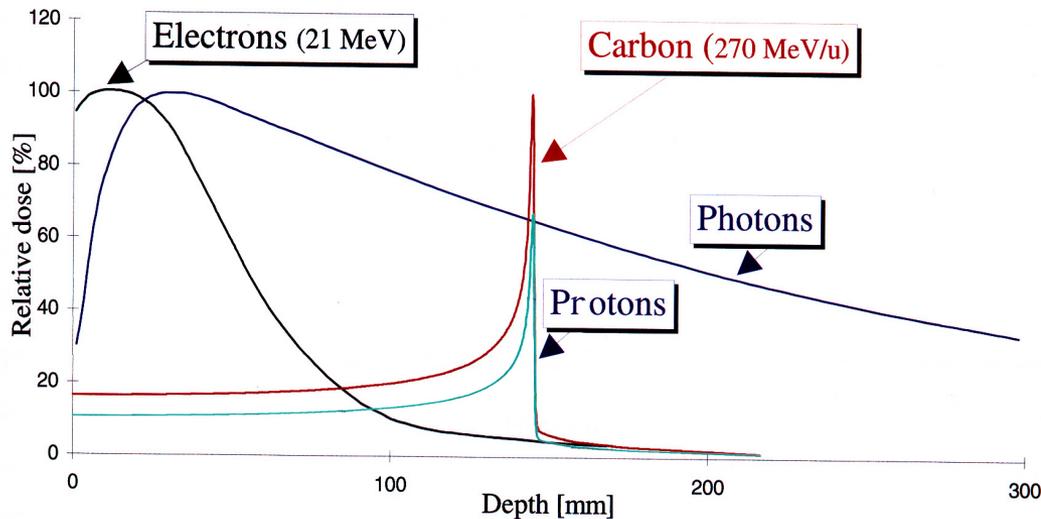
Robert Wilson

# Hadrontherapy

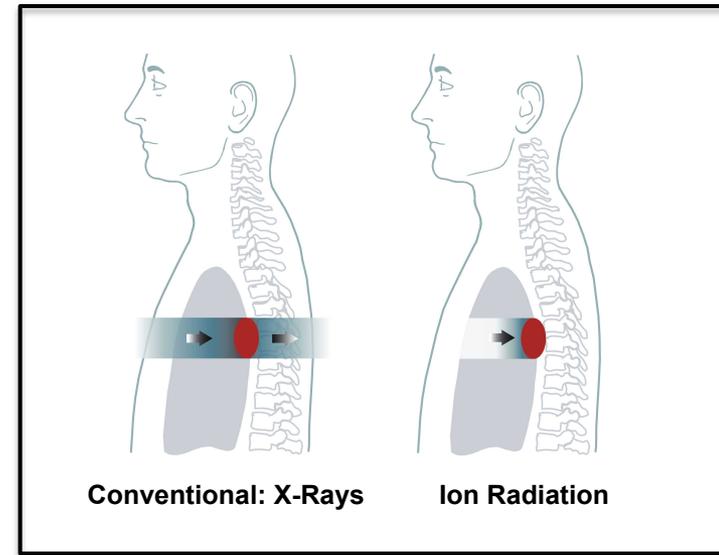
In 1946 Robert Wilson:

- Protons can be used clinically
- Accelerators are available
- Maximum radiation dose can be placed into the tumour
- Particle therapy provides sparing of normal tissues

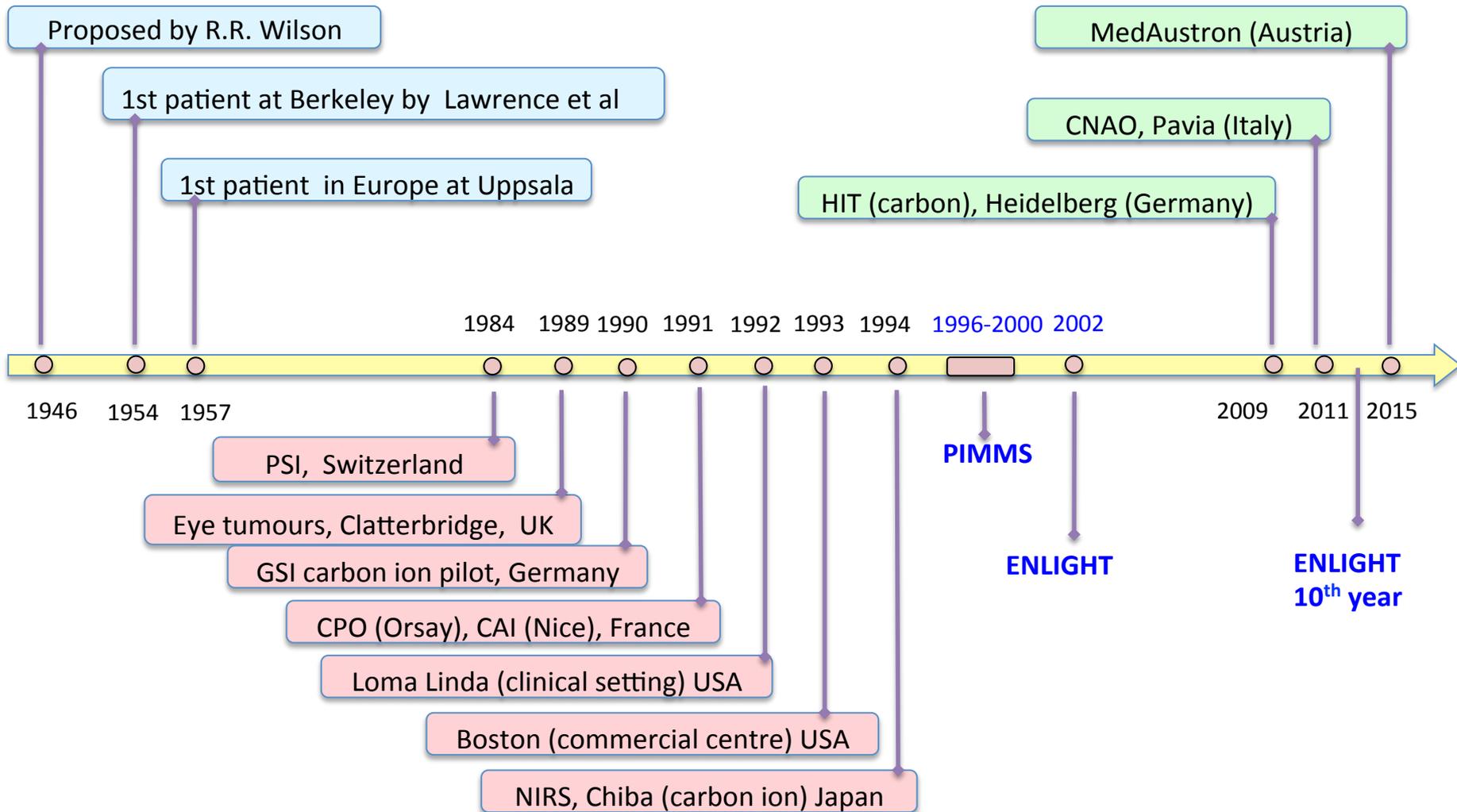
- Tumours near critical organs
- Tumours in children
- Radio-resistant tumours



Depth in the body (mm)



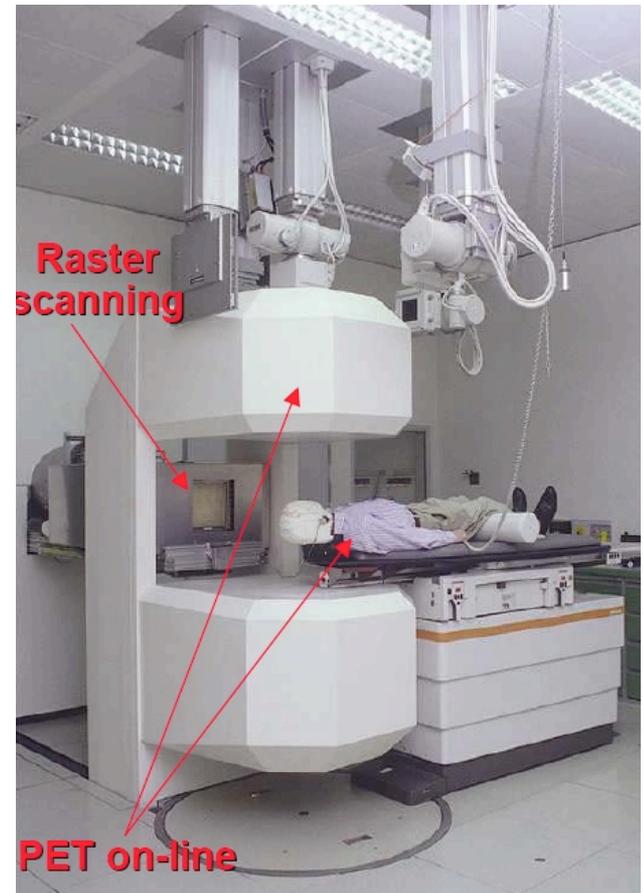
# Particle therapy: a short history



# Carbon ions: pilot project in Europe

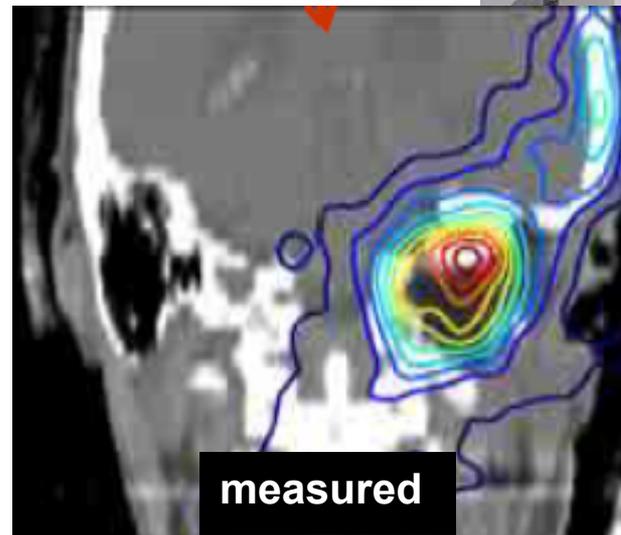
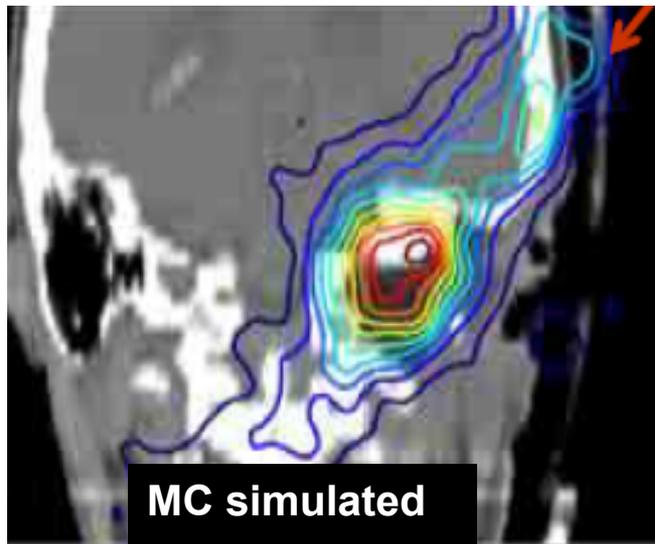
GSI & Heidelberg

– 450 patients treated

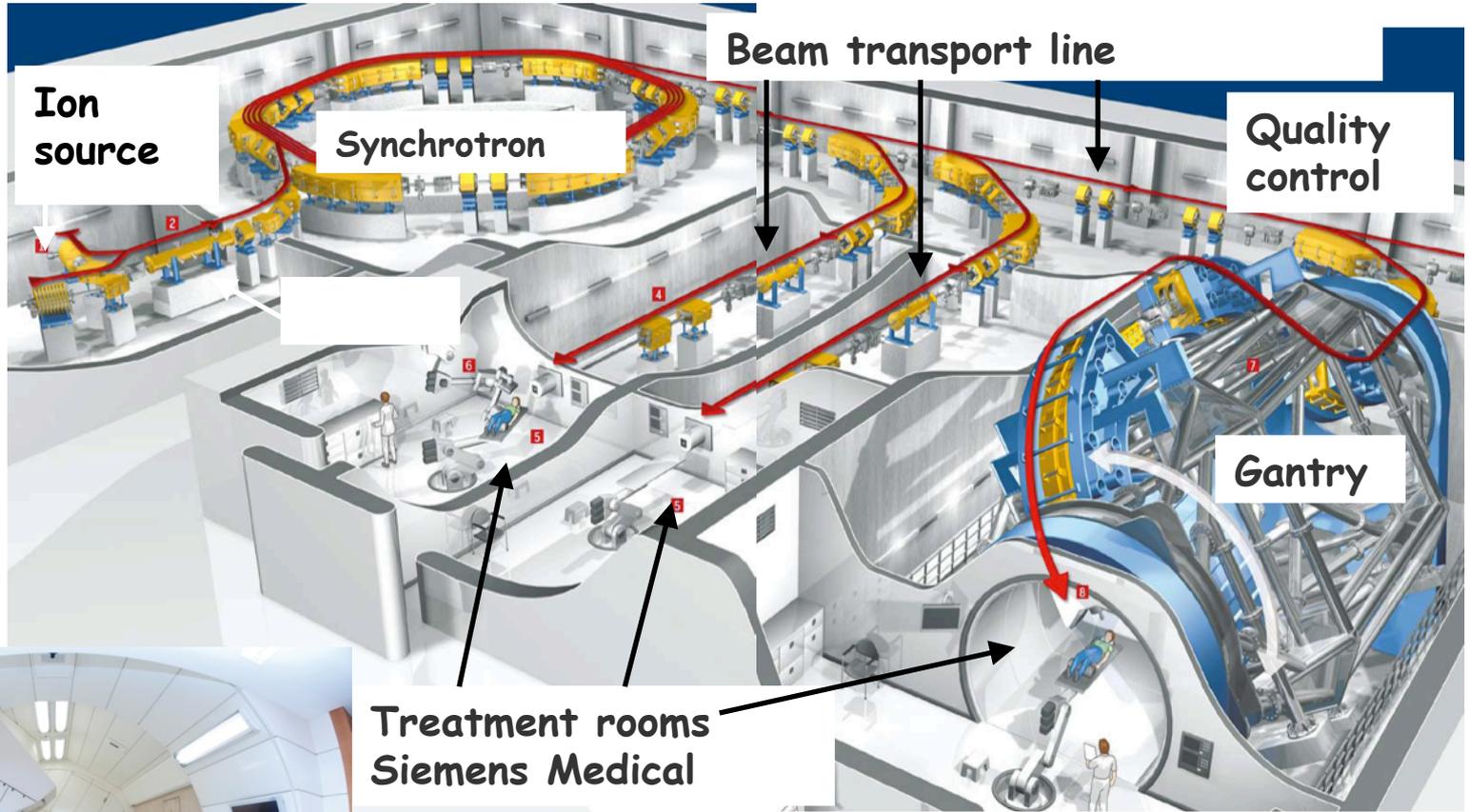


# Real-time monitoring

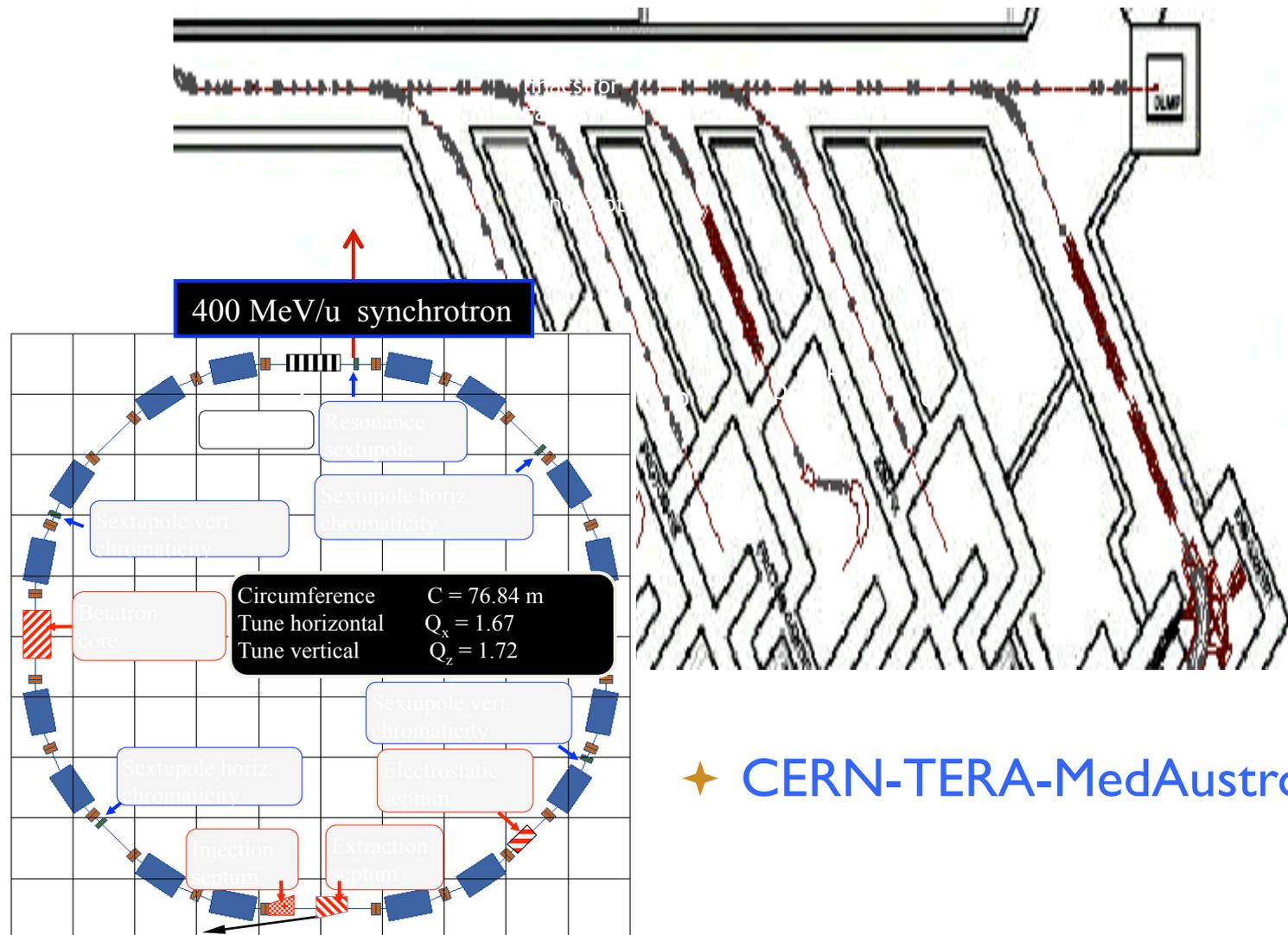
- In-beam PET @ GSI (Germany)
- MonteCarlo simulations
- Organ motion



# HIT - Heidelberg



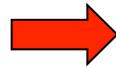
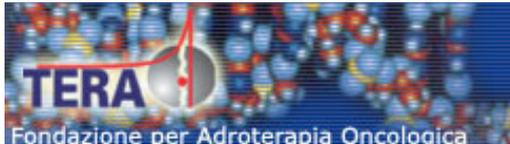
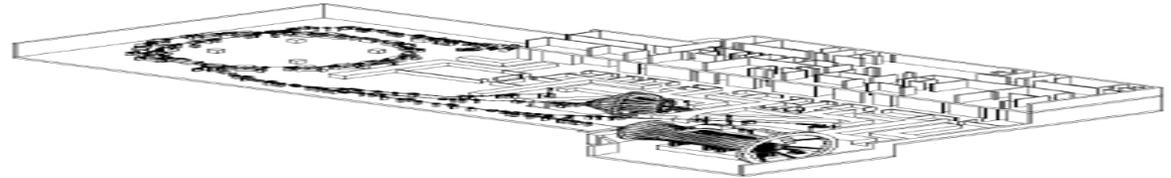
# PIMMS at CERN (1996-2000)



✦ CERN-TERA-MedAustron

# Accelerator Technologies

PIMMS 2000  
(coordinated by CERN)  
has led to:



fondazione **CNAO**

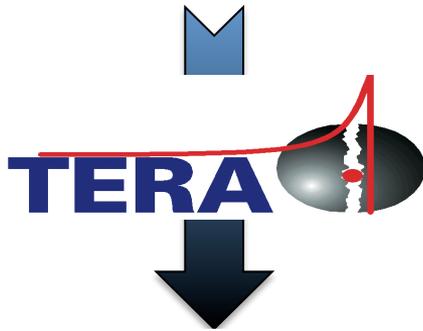
Treatment centre in Pavia, Italy.

**First patient treated with in 2011**

ebg *MedAustron*

Treatment centre in Wiener Neustadt, Austria,  
foundation stone in 2011, installation moved to  
MedAustron at beginning of 2012, first patient in 2015

# From PIMMS study coordinated by CERN



fondazione **CNAO**



*ebg MedAustron*



First patient with carbon ions Nov 2012



Will start treatments in 2016

# MedAustron – Wiener Neustadt



Starts treatment in 2016

# Accelerators in hospitals

Around 9000 of the 17000 accelerators operating in the World today are used for medicine.



HIT, Heidelberg started treating patients in 2009

# Use of Accelerators Today

## General industrial use:

Sterilisation, imaging

## Research Accelerators:

Particles, synchrotron light used in biomedical, physics, chemistry, biology, medical research.

## Radiotherapy:

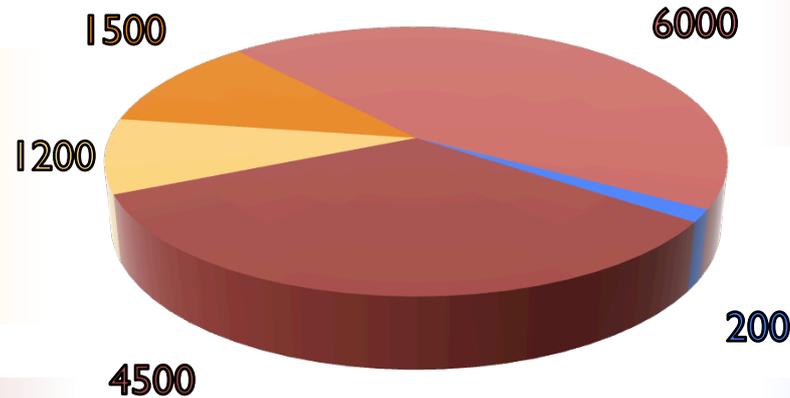
Cancer treatment with X-rays, protons and other particles.

## Ion implantation, surface modifications:

Controlled semiconductor doping; Changing properties of surfaces

## Radioisotope production:

Cancer treatment; imaging organs for medical use.



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~ 9000 of the 17000 accelerators operating in the World today are used for medicine.

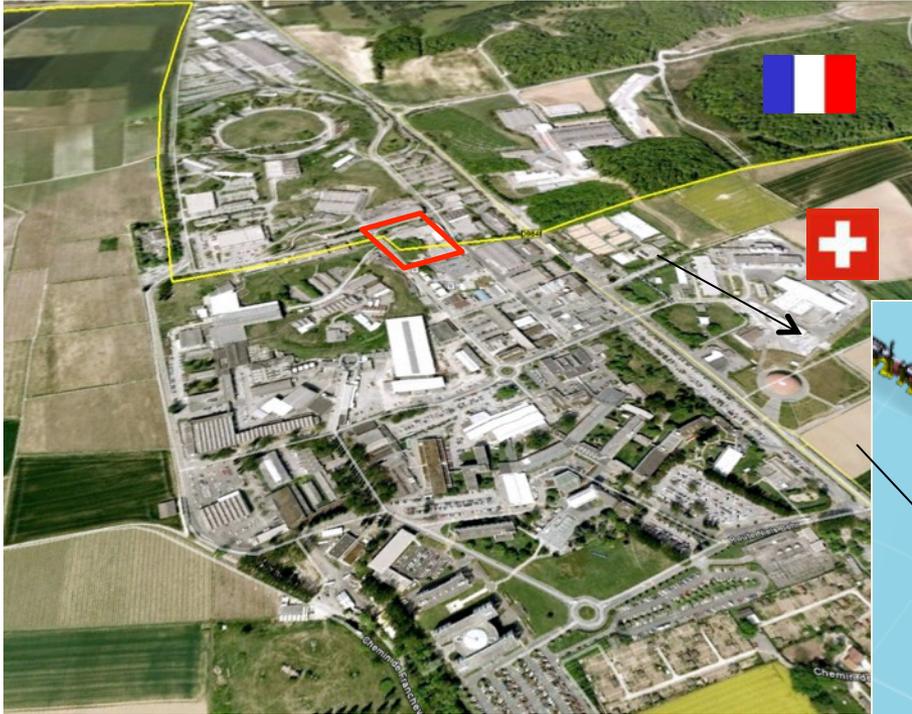


[cern.ch/virtual-hadron-therapy-centre](https://cern.ch/virtual-hadron-therapy-centre)

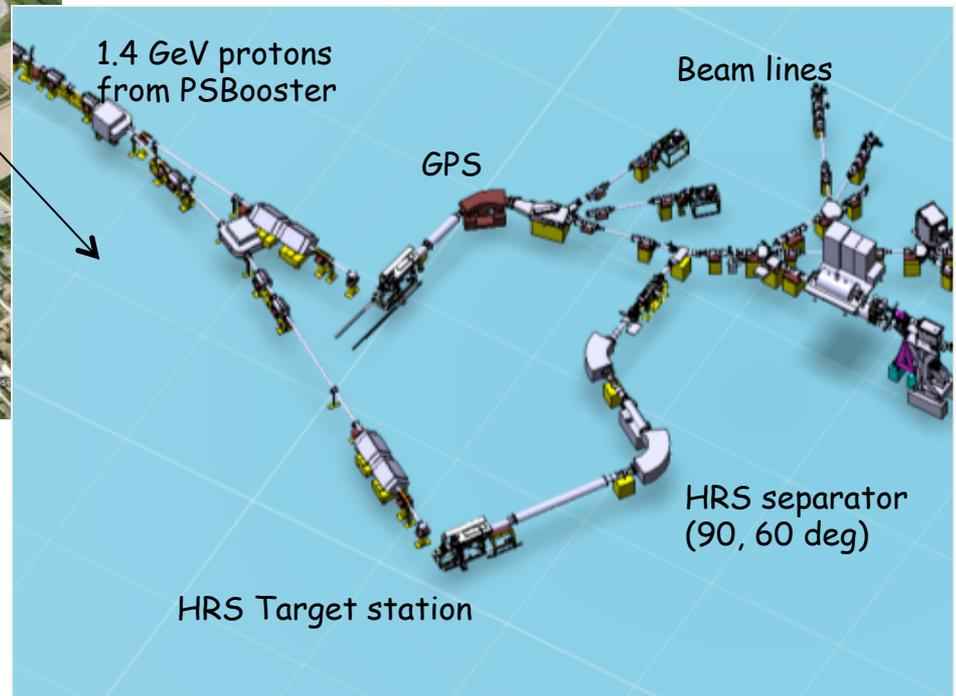
[http://virtual-hadron-therapy-centre.web.cern.ch/virtual-hadron-therapy-centre/  
cern.ch/virtual-hadron-therapy-centre](http://virtual-hadron-therapy-centre.web.cern.ch/virtual-hadron-therapy-centre/cern.ch/virtual-hadron-therapy-centre)

# ISOLDE

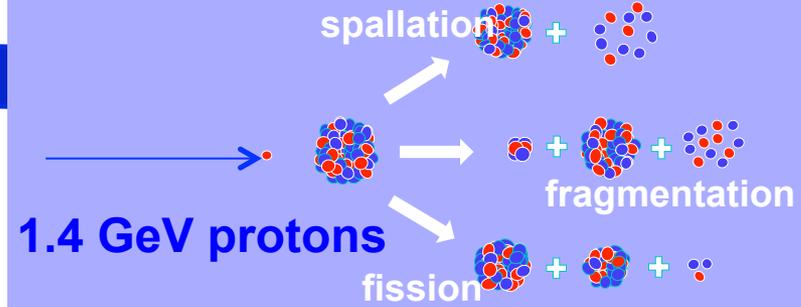
isotopes for detection & treatment



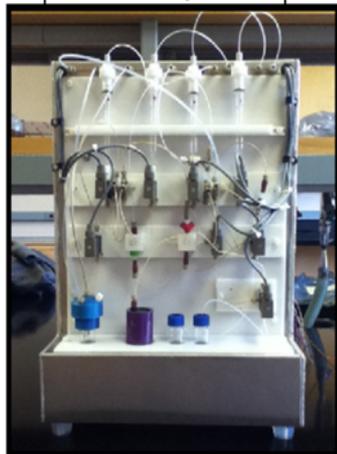
In collaboration with  
University Hospital Geneva



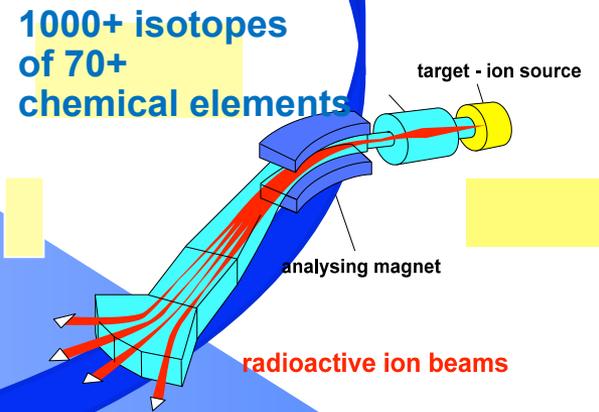
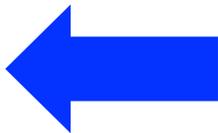
# MEDICIS



## Chemical separation



H

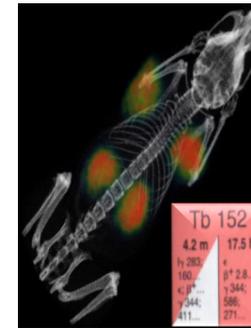


# Terbium: Swiss Army Knife of Nuclear Medicine

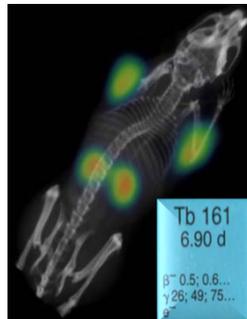
**$^{149}\text{Tb}$ -therapy**



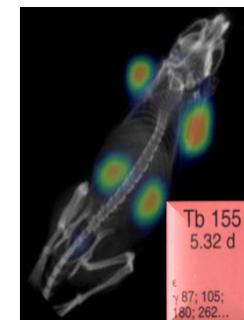
**$^{152}\text{Tb}$ -PET**



**$^{161}\text{Tb}$ -therapy  
& SPECT**



**$^{155}\text{Tb}$ -SPECT**



ISOLDE

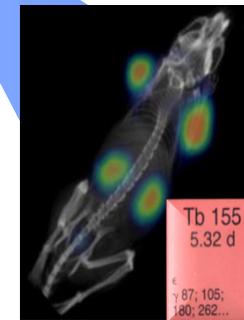
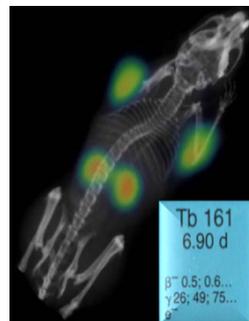
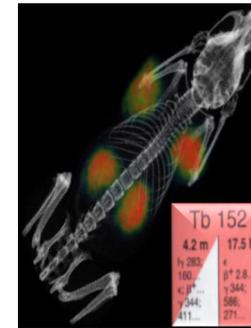
PAUL SCHERRER INSTITUT  
PSI

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NEUTRONS  
FOR SCIENCE

Müller et al., JNM 2012



# Terbium: Swiss Army Knife of Nuclear Medicine

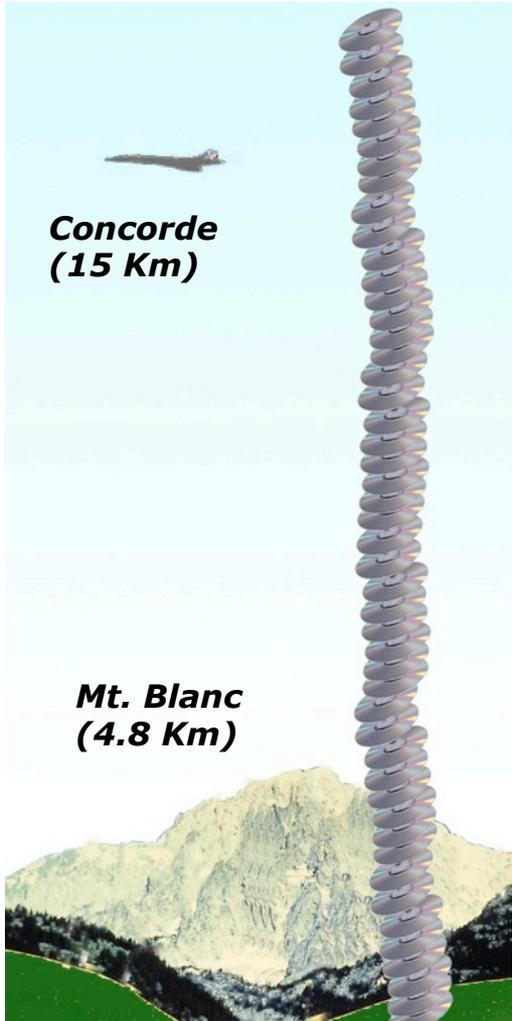


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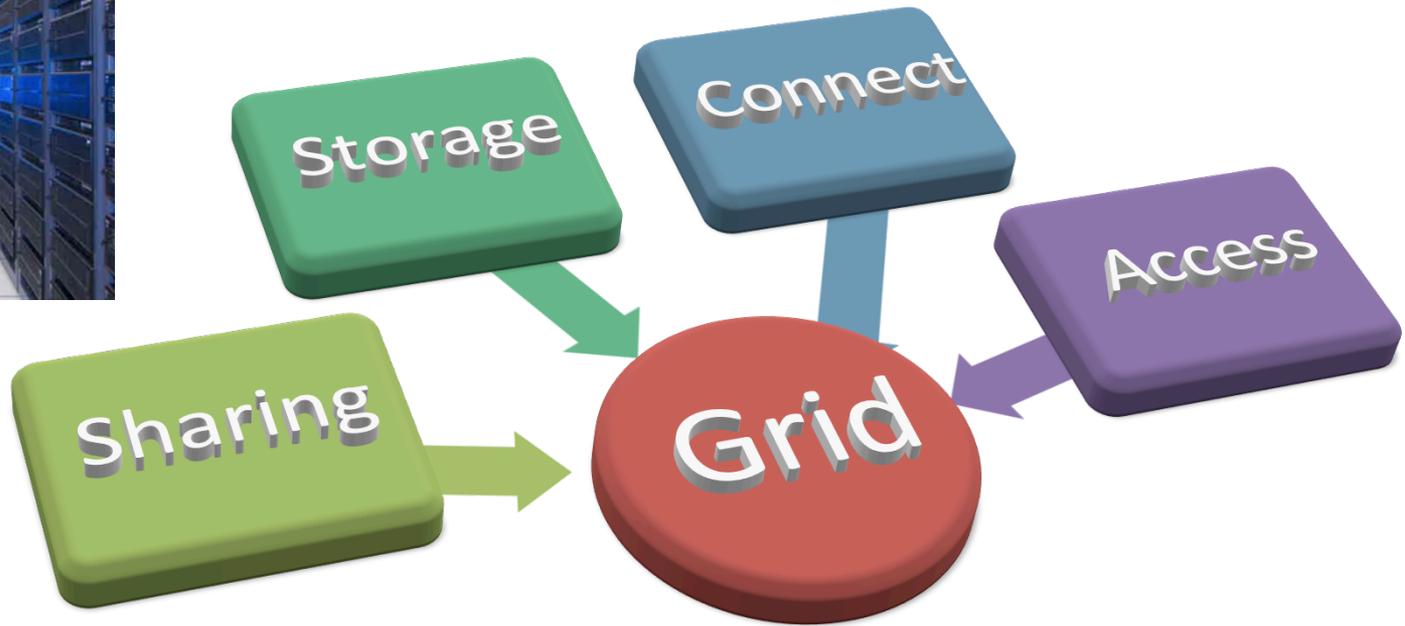


Müller et al., JNM 2012

# Computing for medical applications



# The Grid

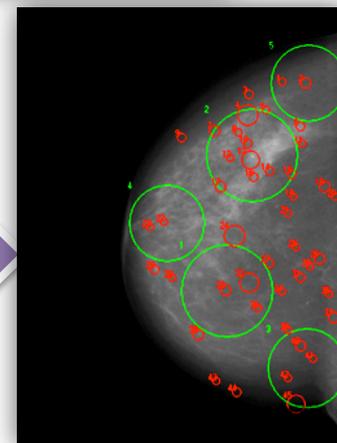
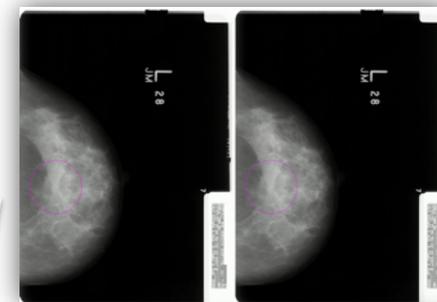
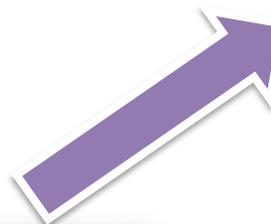


Data and Resources



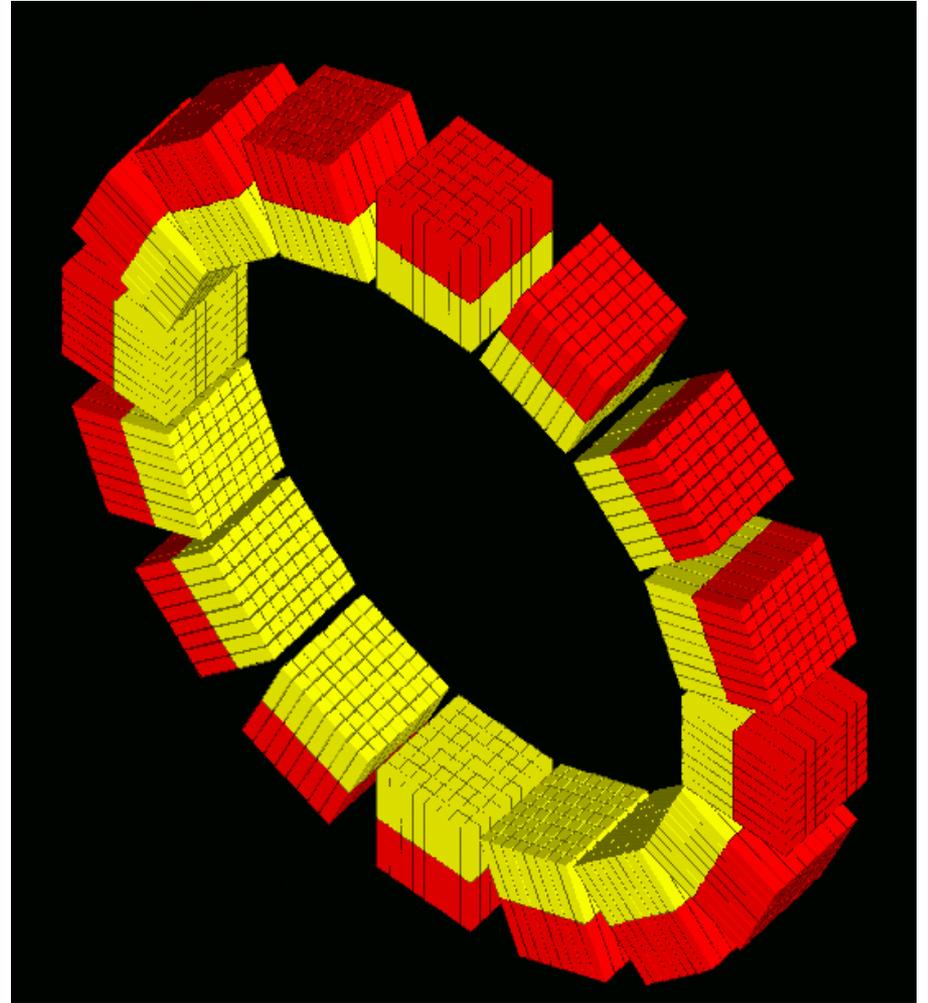
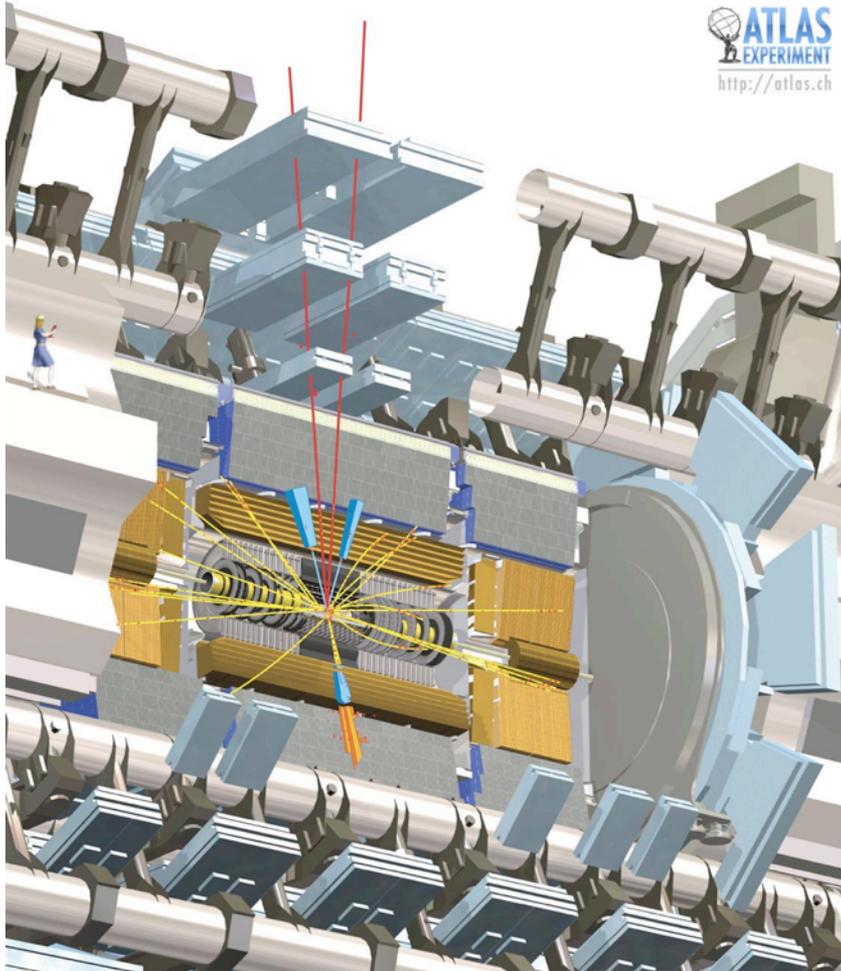
# Mammogrid - a grid mammography database

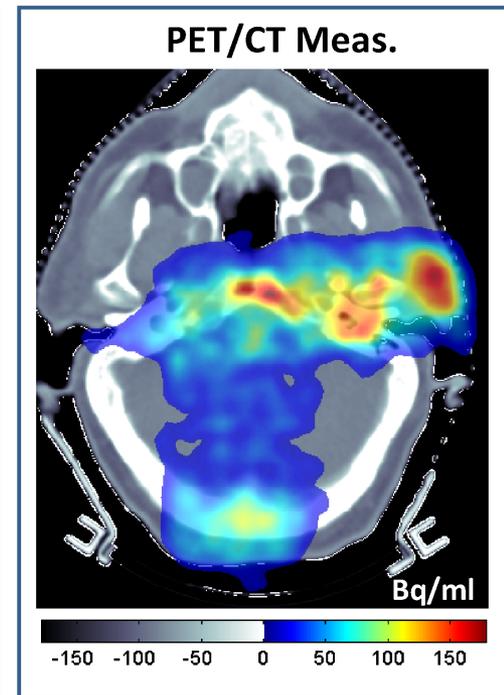
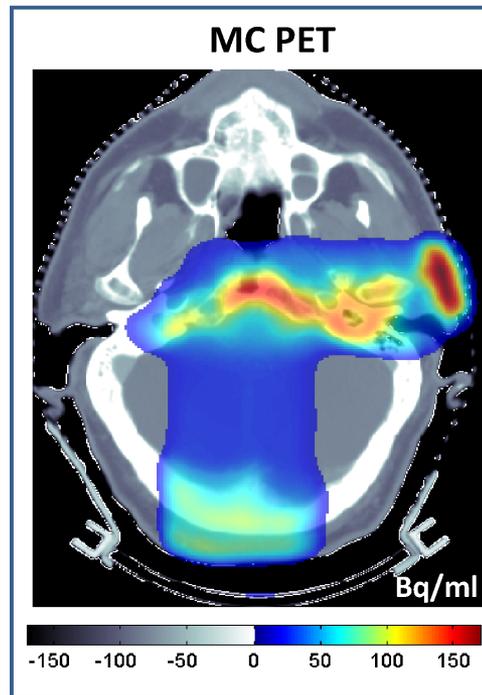
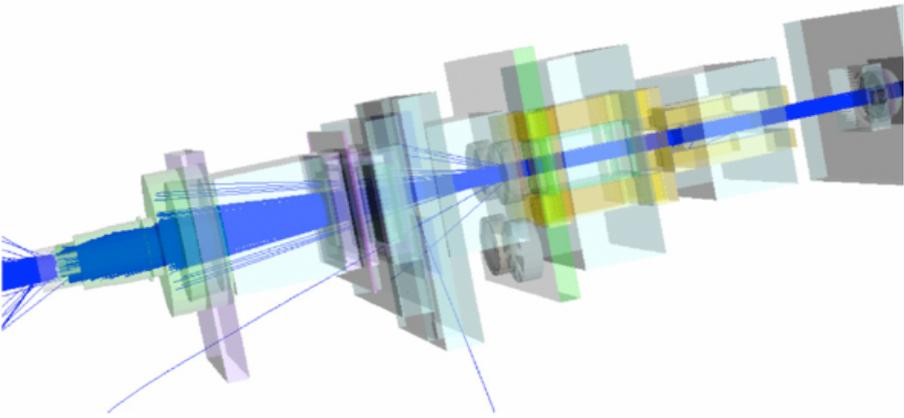
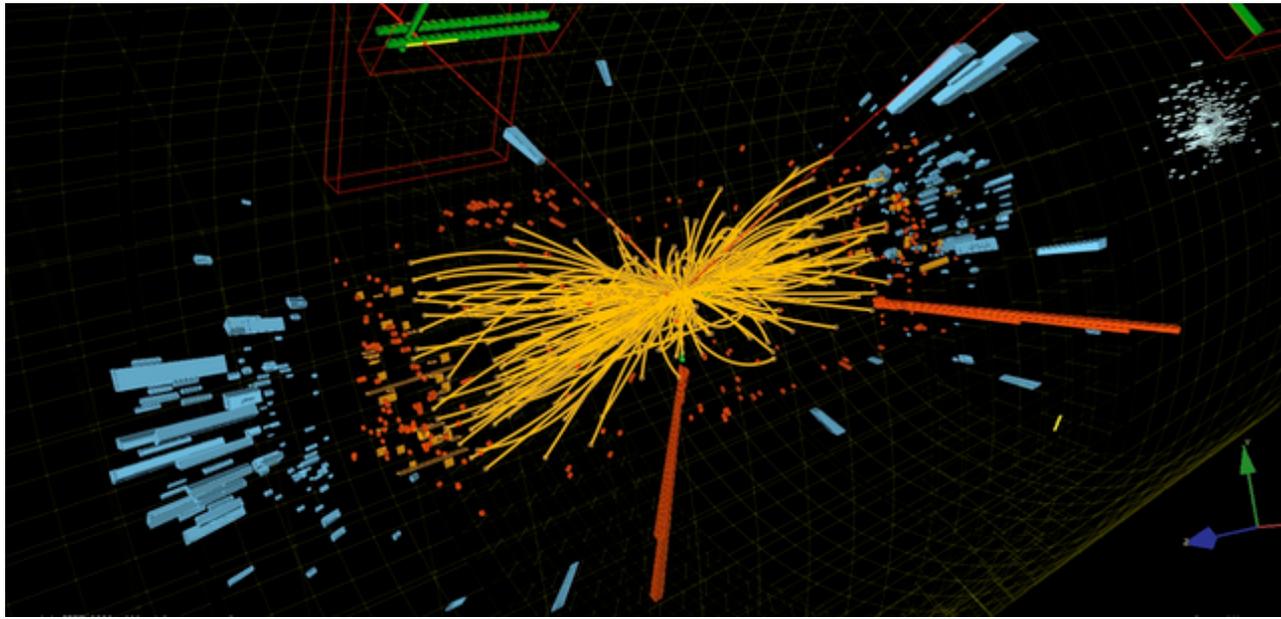
- Second Opinion
- Cancer Screening
- Education and Training
- Reference Database / Repository



From: David MANSET, CEO MAAT France, [www.maat-g.com](http://www.maat-g.com)

# Simulation

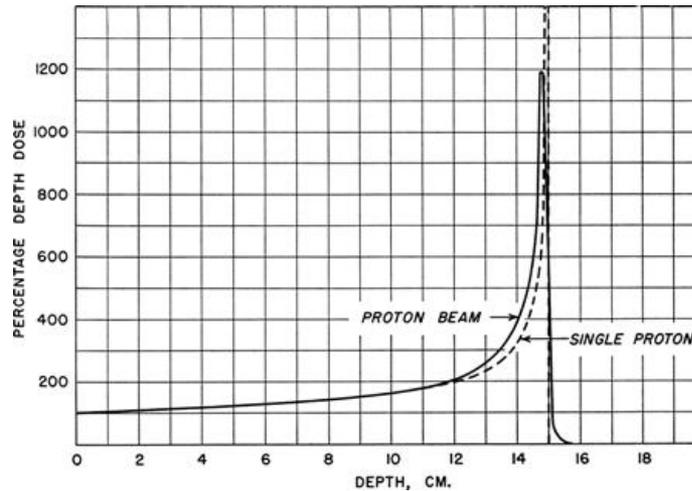




# From physics...



**1932** - first cyclotron developed by Ernest Lawrence

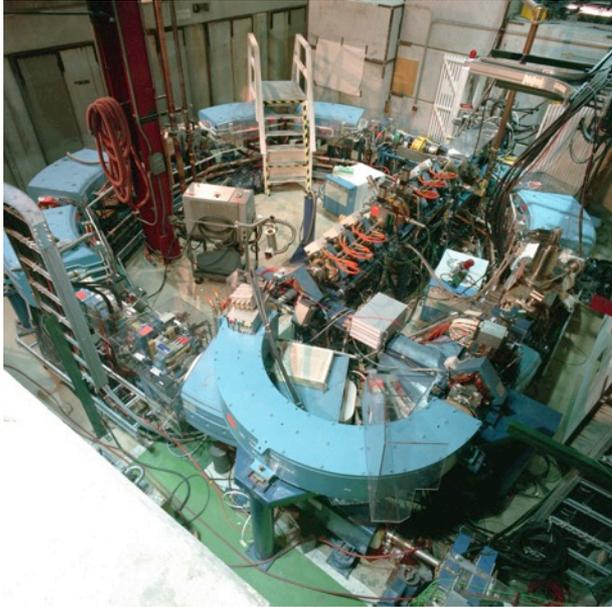


**1946** - proton therapy proposed by Wilson, exploiting the properties of the Bragg peak



**1954** - Berkeley treats the first patient and begins extensive studies with various ions

# ...to clinics



**1993** - patients treated at first hospital-based facility at Loma Linda



**1994** - first facility dedicated to carbon ions operational at HIMAC Japan



**1997** - First patient treated with carbon ions at GSI



## Imaging Animation for ENVISION

*<http://cds.cern.ch/record/1611721>*

# References

- [cern.ch/crystalclear](http://cern.ch/crystalclear)
- [cern.ch/enlight](http://cern.ch/enlight)
- [cern.ch/virtual-hadron-therapy-centre](http://cern.ch/virtual-hadron-therapy-centre)
- <http://cds.cern.ch/record/1611721>
- [cern.ch/knowledgetransfer](http://cern.ch/knowledgetransfer)
- [cern.ch/medipix](http://cern.ch/medipix)
- [cern.ch/twiki/bin/view/AXIALPET](http://cern.ch/twiki/bin/view/AXIALPET)
- [cern.ch/medaustrotron](http://cern.ch/medaustrotron)
- [cern.ch/fluka/heart/rh.html](http://cern.ch/fluka/heart/rh.html)
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- [cern.ch/wwwasd/geant](http://cern.ch/wwwasd/geant)
- [cern.ch/wwwasd/geant/tutorial/tutstart.html](http://cern.ch/wwwasd/geant/tutorial/tutstart.html)